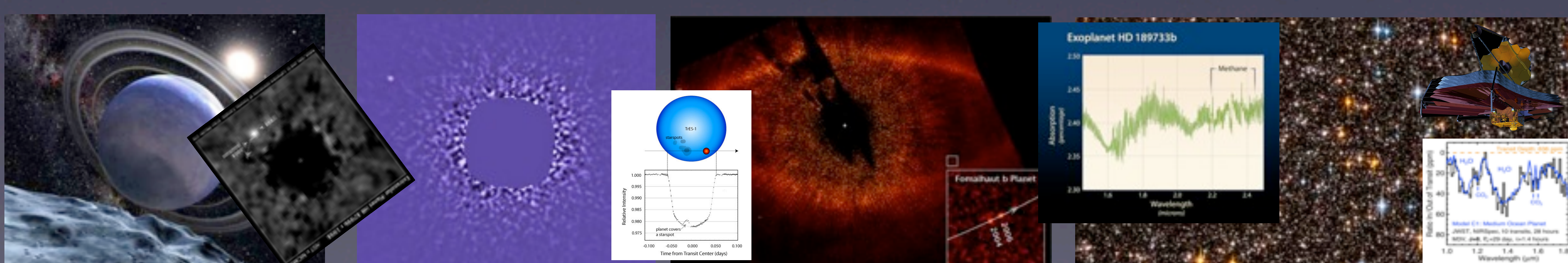
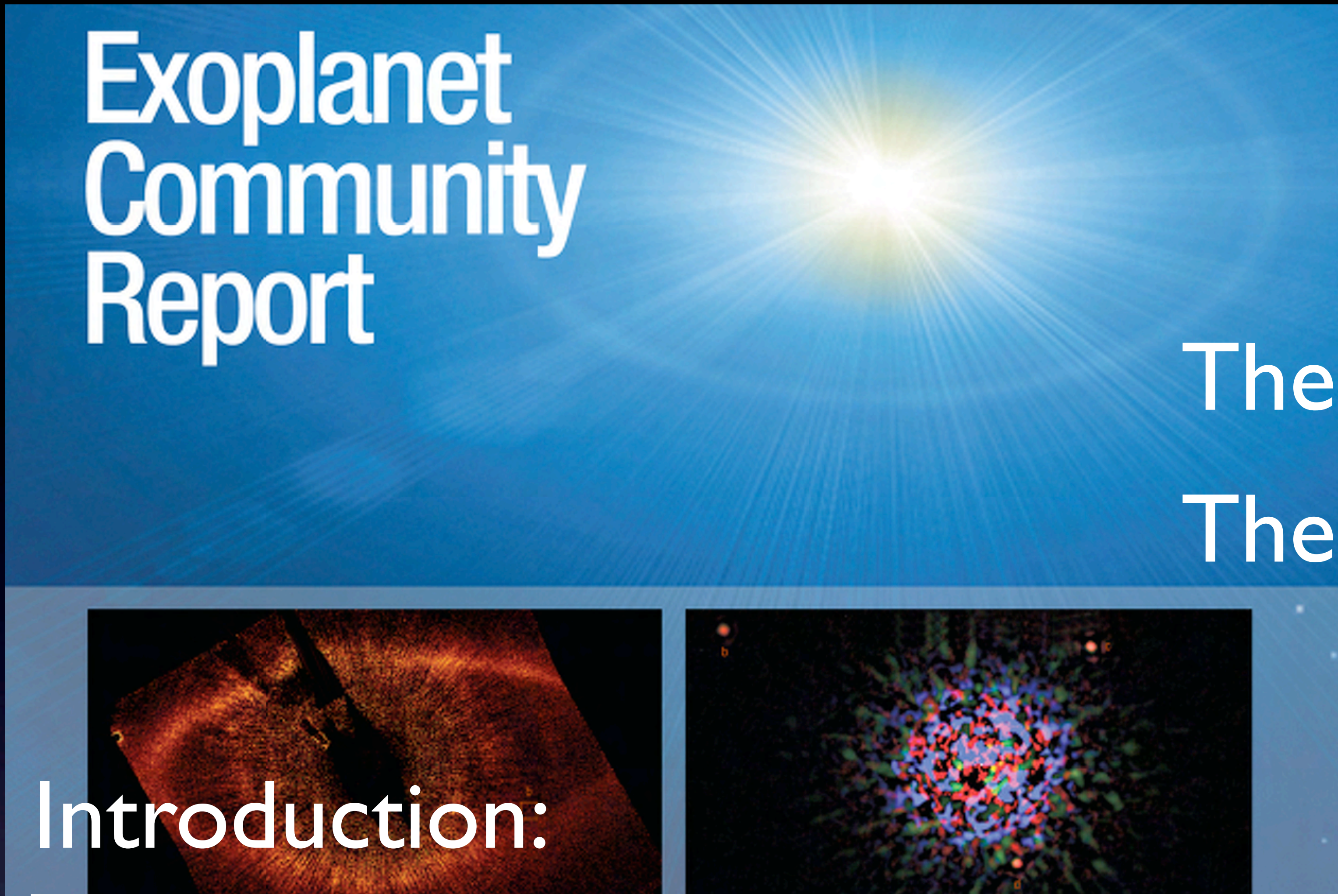
Characterizing Exoplanets - a view from Baltimore

Matt Mountain
Space Telescope Science Institute & JHU



The science is compelling

The technology is here



The science is compelling

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Introduction:

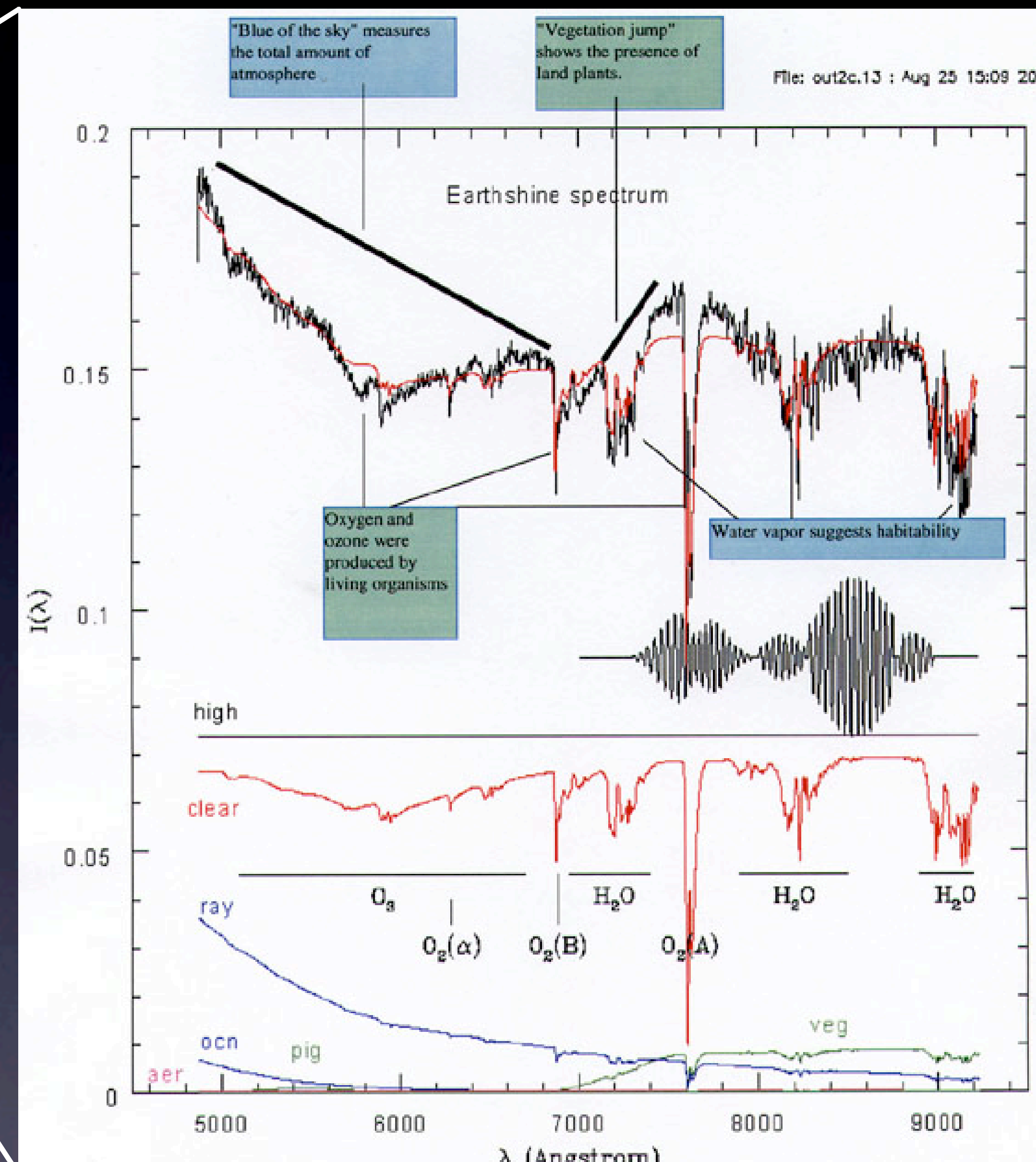
It is ironic that what is arguably the most compelling subject in astronomy—the search for other worlds and other life beyond our Solar System—emerges only now, in the 21st Century. Four centuries of discovery have brought us a remarkable understanding of the birth and evolution of stars, the history of galaxies, and even cosmology—the development of the entire universe, but now it seems that the first shall be last. Not for a lack of imagination or motivation, but simply for the want of technology, our oldest and deepest questions, the ones most relevant to our own origins and fate, have remained beyond our grasp for thousands of years.

We are indeed fortunate to live in the time when this last barrier to our search is falling. It

is the technology here ?

assumption 1 of 2

Is there life on this planet?

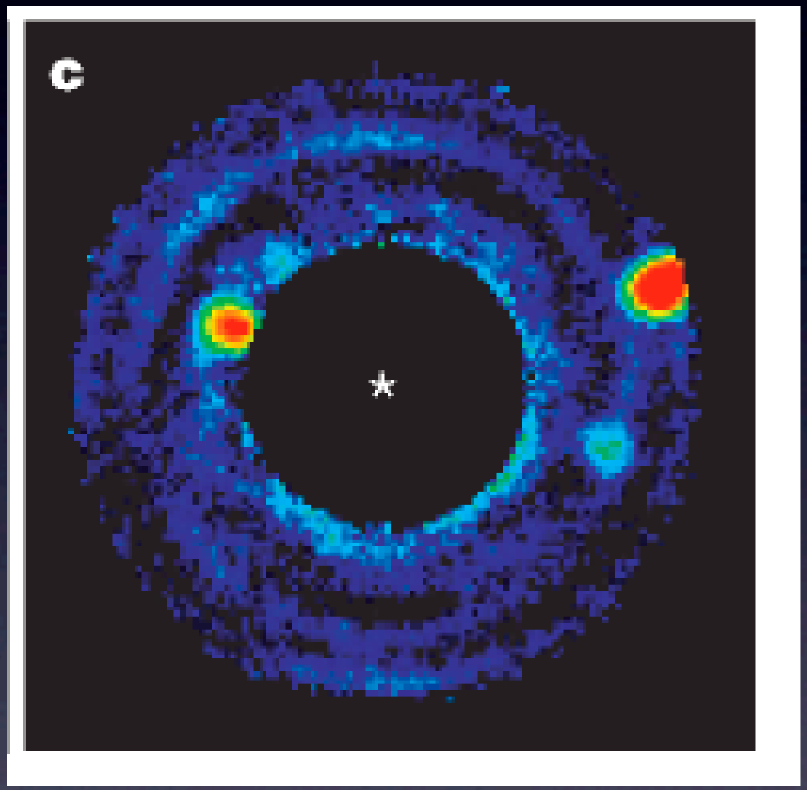


We require spectra of 29 ~30 m_v sources

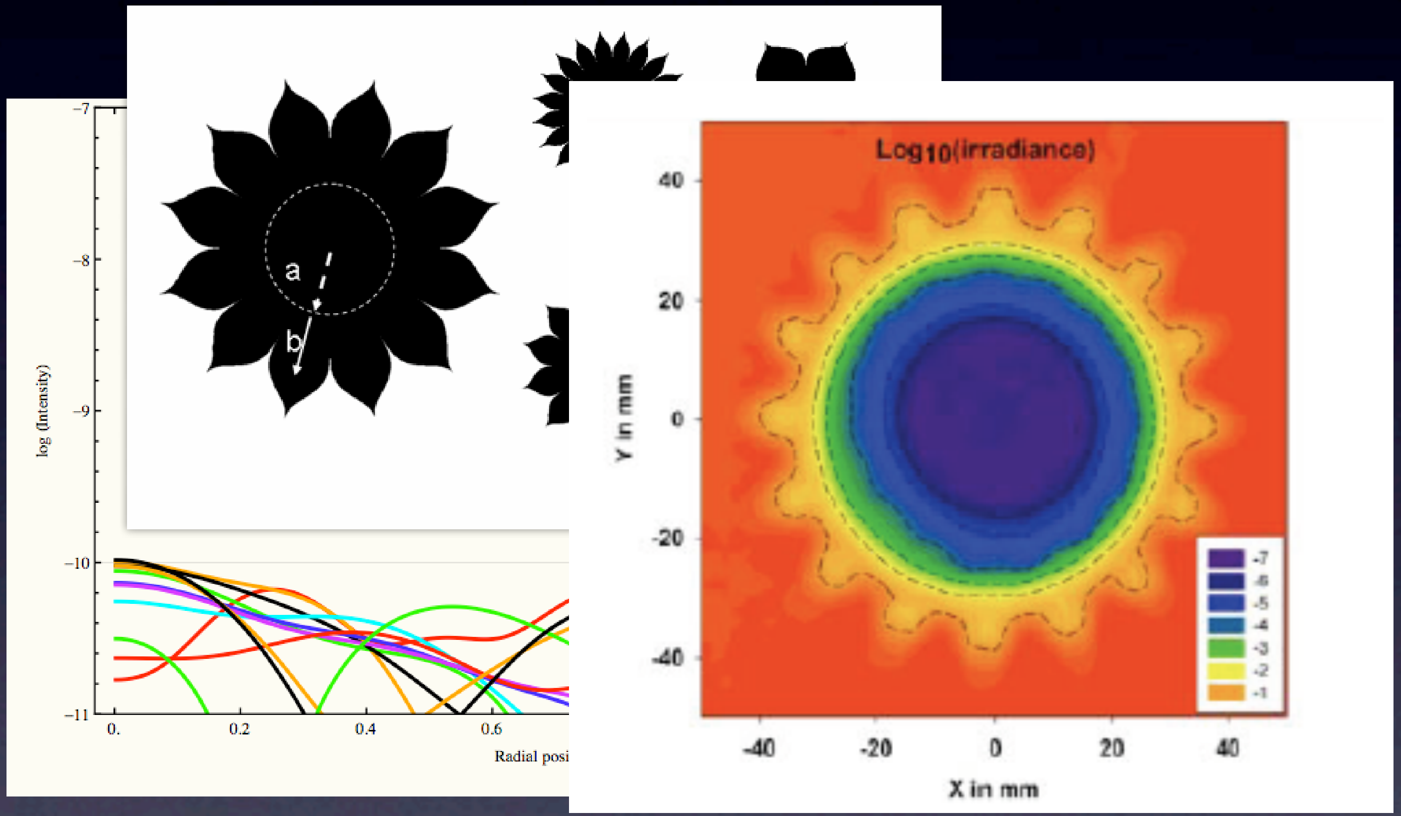
By 2020 "pale blue dots" will be necessary but not sufficient scientific motivation we will need spectra is the technology here ? assumption 2 of 2

Coronagraph

Free flying star-shade



Trauger & Traub Nature Letters, April 2007



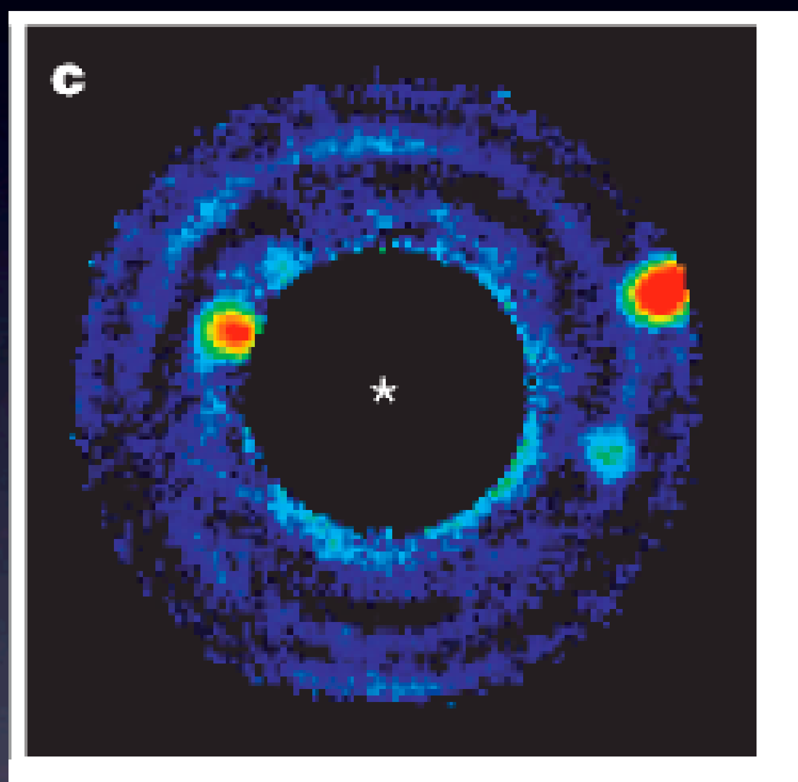
Cash, Soummer, various, 2008, Leviton et al. 2007; Schindhelm et al. 2007

Starlight suppression to $\sim 10^{-10}$
is a solvable problem **from Space**

is the technology here ?

assumption 2 of 2

Coronagraph



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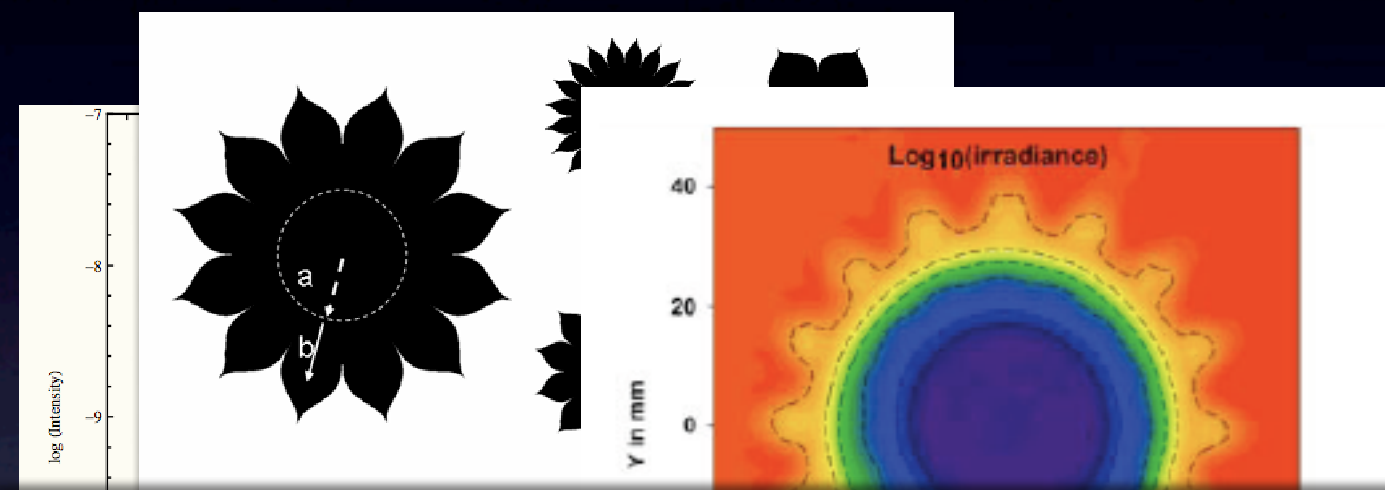

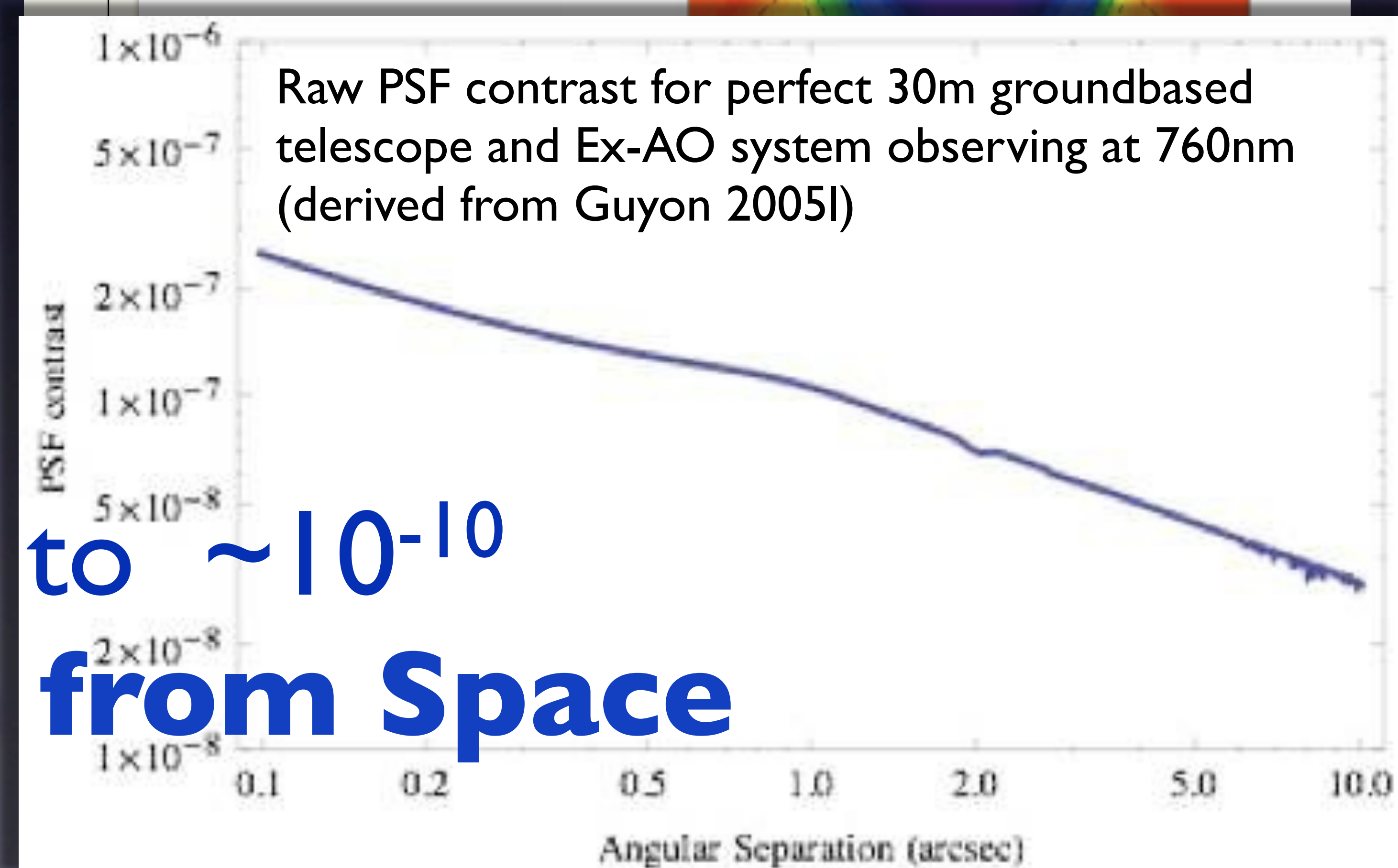

Starlight suppression to $\sim 10^{-10}$
is a solvable problem from Space

Observable Drake Equation – after Reid & Hawley

$N_{L,T}$ is the number of life bearing planets at time T

$$\boxed{N_{L,T} = N_{*,T}\, p_p\, n_e\, p_w\, p_l}$$

Observable

Number of stars @ T: $N_{*,T} = SRF(t) *\Psi(m) *\Lambda(m,t)$

Prob. of planet system: $p_p = f(Z, m)$

No. of terrestrial planets $n_e = n\,(0.1m_e < m_p < 10\, m_e)$

Prob. of liquid water $p_w = f(\bar{n}_b, \varepsilon, r_{orbit}, L_*)$

Prob. of life p_l

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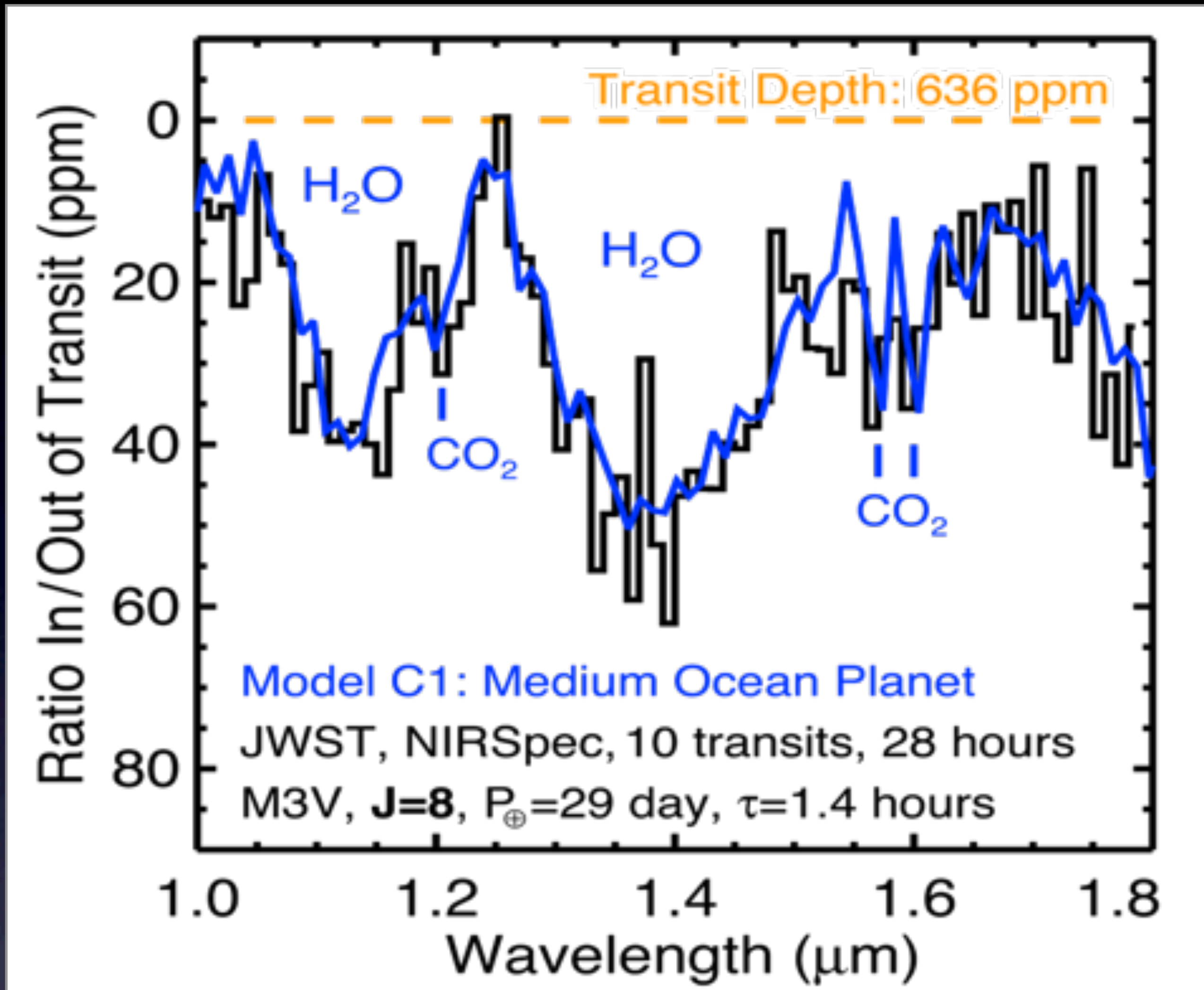
Prob. of life p_l ?

Transit Spectra of a Habitable Ocean Planet



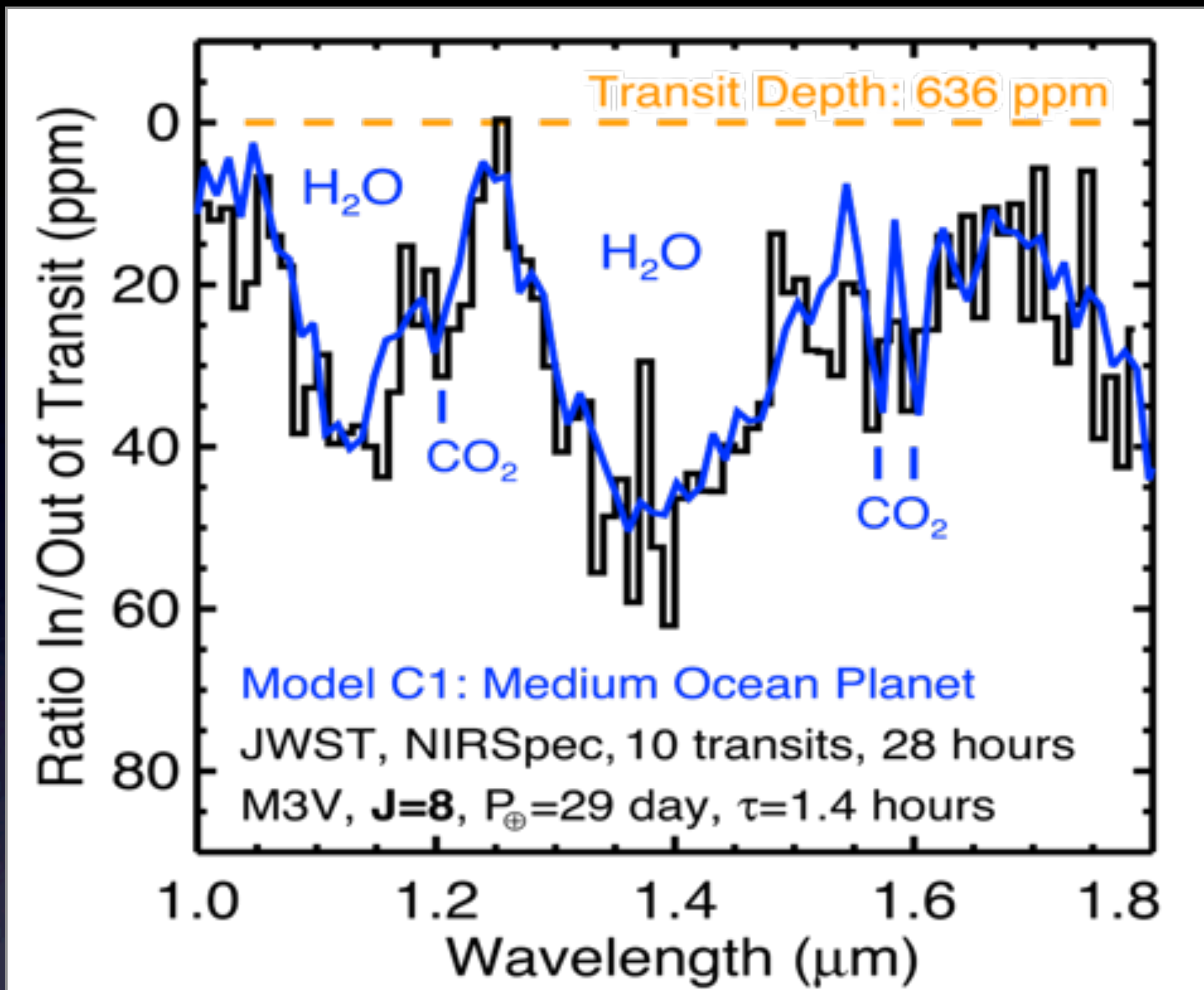
Gliese 581 (M3V, J=6.7)

- b: 5.4 days, 15.6 $M_\oplus$
- c: 12.9 days, 5.1 $M_\oplus$
- d: 83.4 days, 8.3 $M_\oplus$

Find one that transits…

- 6000 M dwarfs with J<10
- Habitable → 11% transit
- Up to 70 transits for J<10

Transit Spectra of a Habitable Ocean Planet



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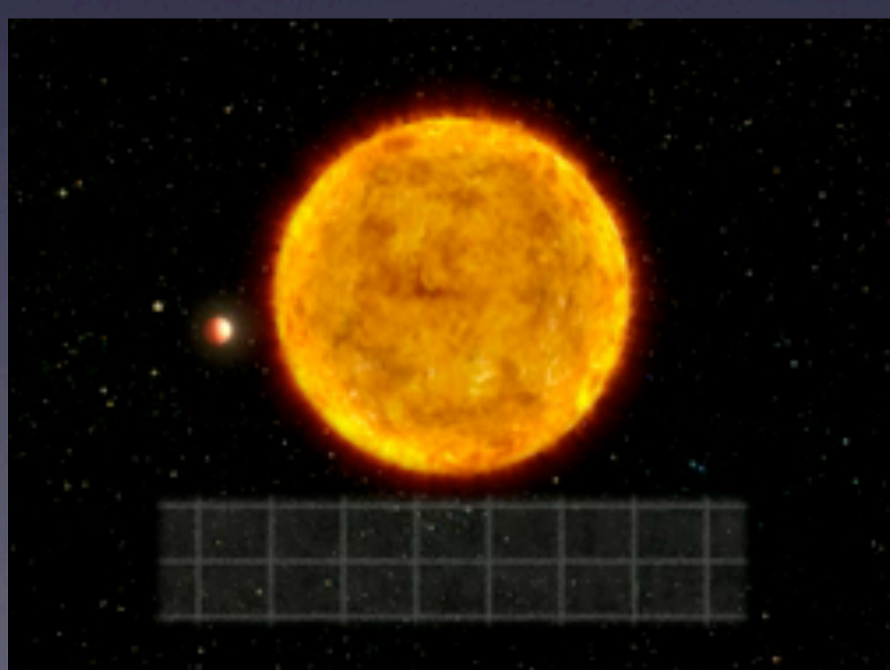

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how big a space telescope do we need to solve the Observable Drake Equation?

$$N_{L,T} = N_{*,T}\, p_p\, n_e\, p_w\, p_l$$

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Number of stars @ T: $N_{*,T} = SRF(t) * \Psi(m) * \Lambda(m,t)$ ✓

Prob. of planet system: $p_p = f(Z, m)$ ✓

No. of terrestrial planets $n_e = n\,(0.1 m_e < m_p < 10\, m_e)$ ✓

✓

Prob. of liquid water $p_w = f(\bar{n}_b, \varepsilon, r_{orbit}, L_*)$

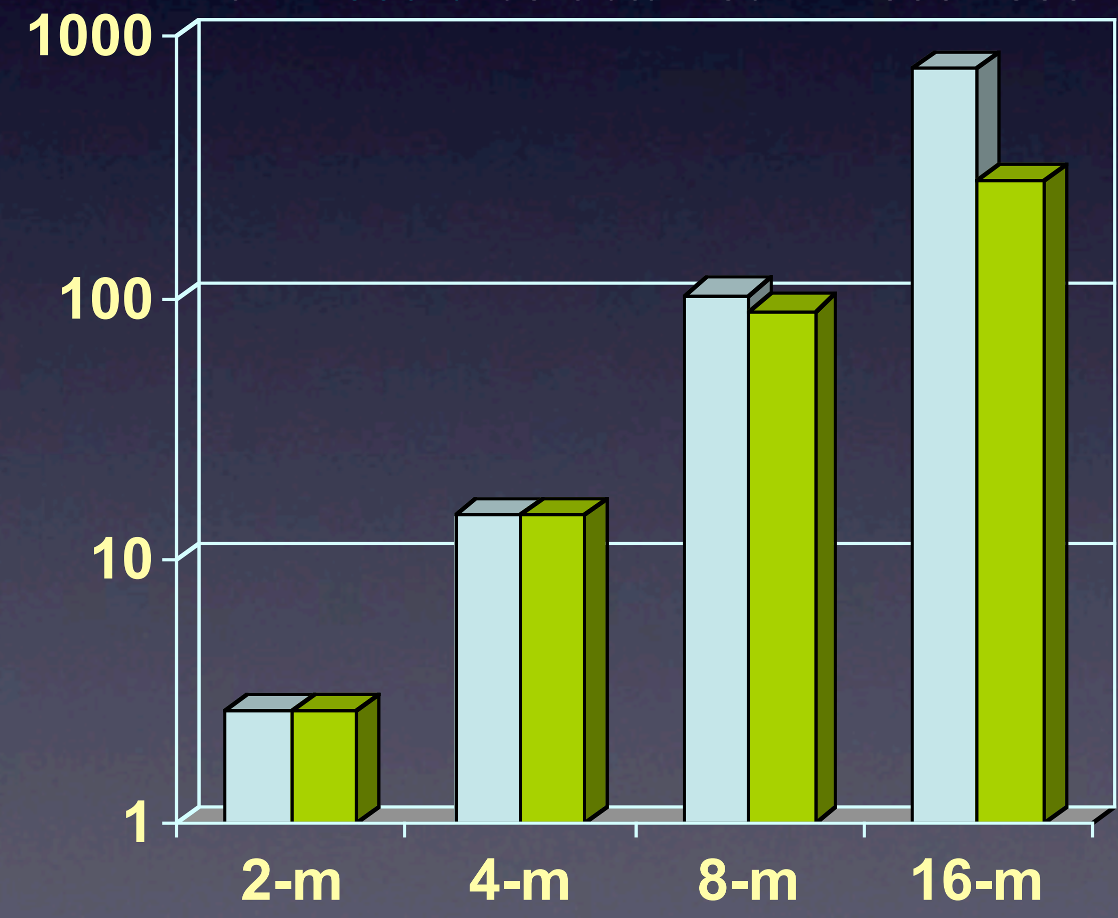
$$N_{L,T} = N_{*,Observed} \cdot \eta_{earth} \cdot p_l$$

We know where all the stars are
- how many could we search for earths ?

Green bars show the number of FGK stars that could be observed 3x each in a 5-year mission without exceeding 20% of total observing time available to community.

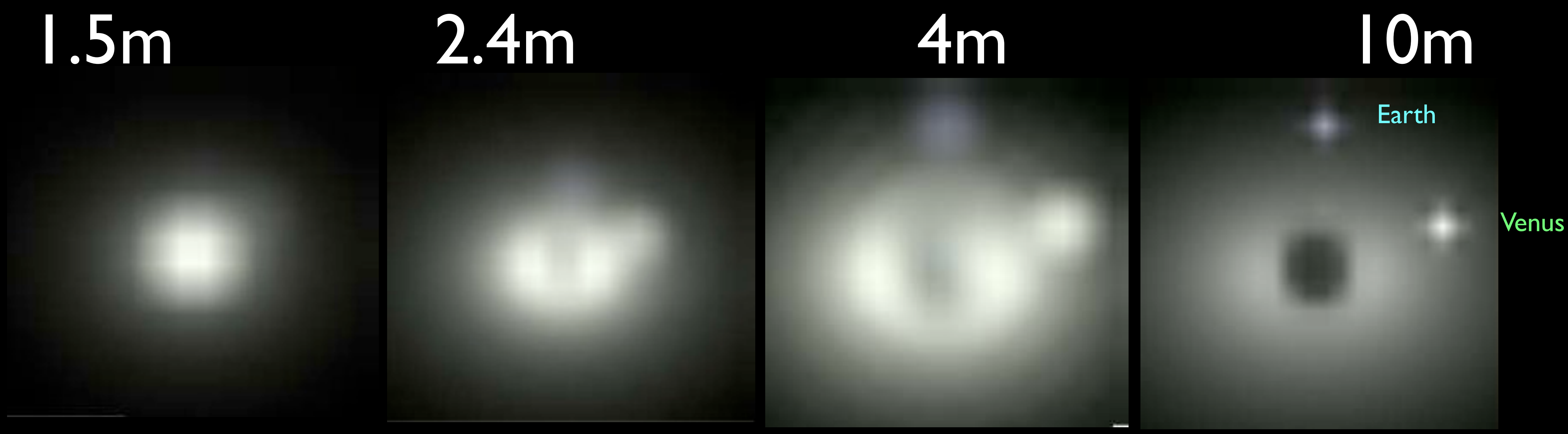
Need to multiply these values by η_{Earth} x f_B to get the number of potentially life-bearing planets detected by a space telescope.
η_{Earth} = fraction of stars with Earth-mass planets in HZ
f_B = fraction of the Earth-mass planets that have detectable biosignatures

Number of FGK stars for which SNR=10, R=70 spectrum of Earth-twin could be obtained in <500 ksec



Characterizing Exoplanets from Space

Credit: Web Cash 2008



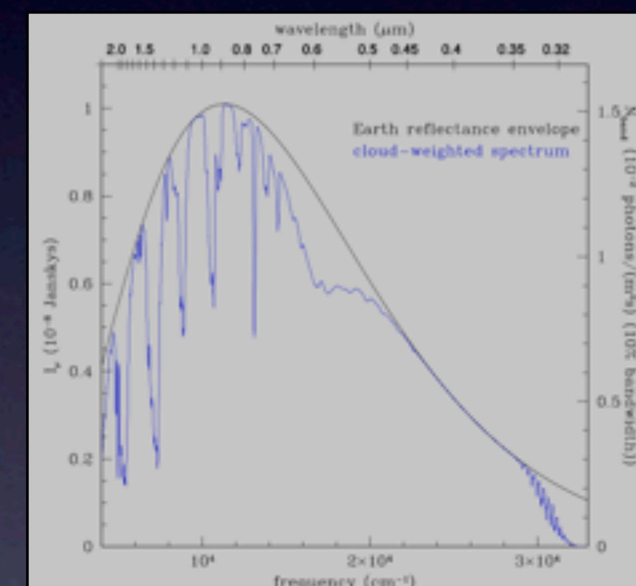
Above: a simulation of our solar system at a distance of 10 pc observed with an external occulter and a telescope with the indicated aperture size. The two planets are Earth and Venus.

characterizing, and discriminating terrestrial scale planets
from their parent star
requires aperture and angular resolution

Courtesy ATLAST Team

how big a space telescope do we need to solve the Observable Drake Equation?

$$N_{L,t} \sim D_{Tel}^{\ 3} \cdot \eta_{earth} \cdot \ p_L$$

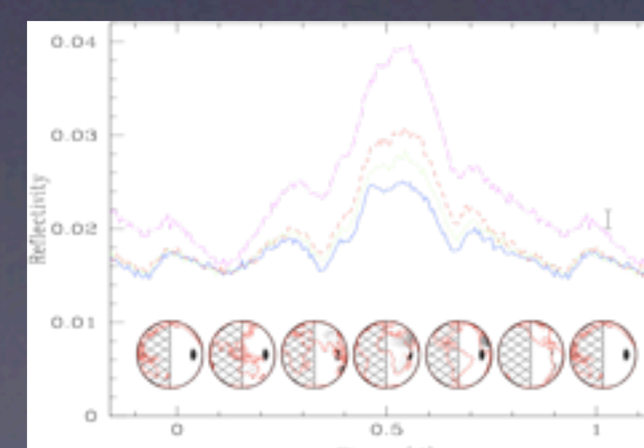


If: $\eta_{earth} \cdot p_L \sim 1$ then $D_{tel} \sim 4m$

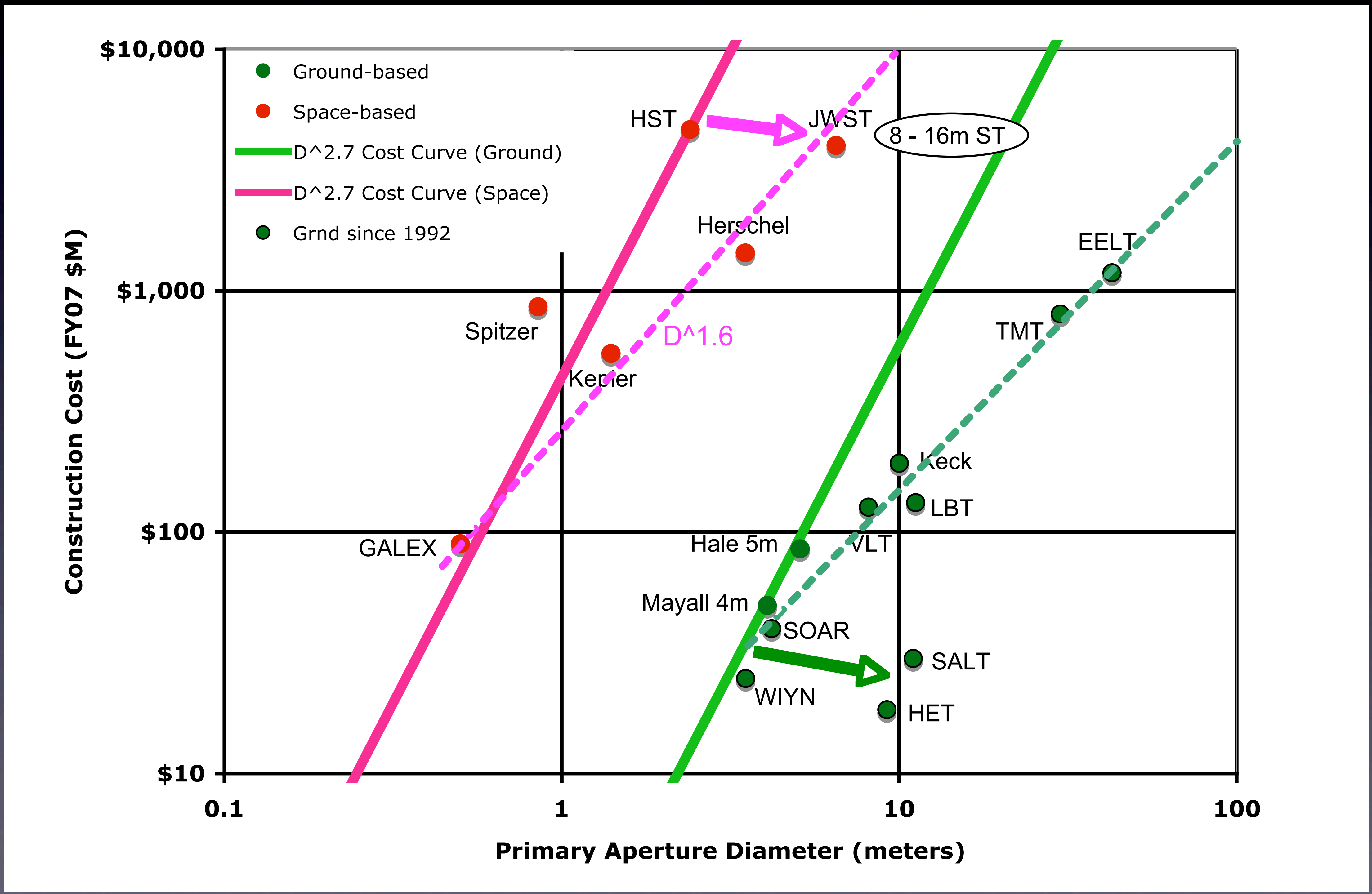
$\eta_{earth} \cdot p_L < 1$ then $D_{tel} \sim 8m$

$\eta_{earth} \cdot p_L << 1$ then $D_{tel} \sim 16m$

(assuming fixed zodiacal contribution)

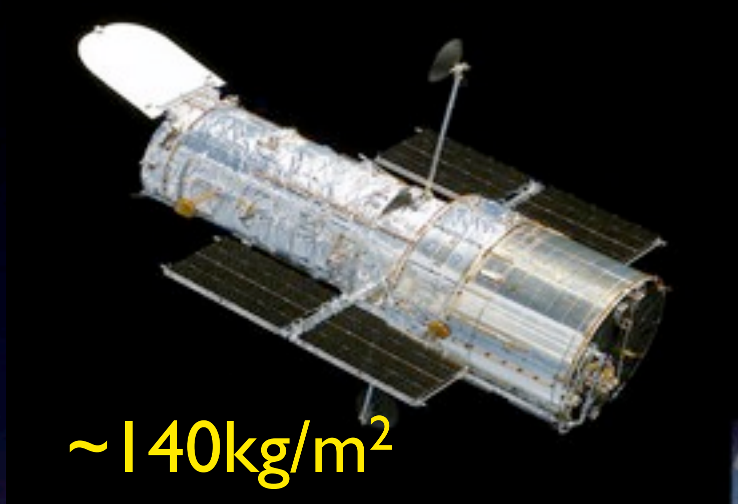


cost does not follow a fixed scaling relation with aperture as technology or architecture advance



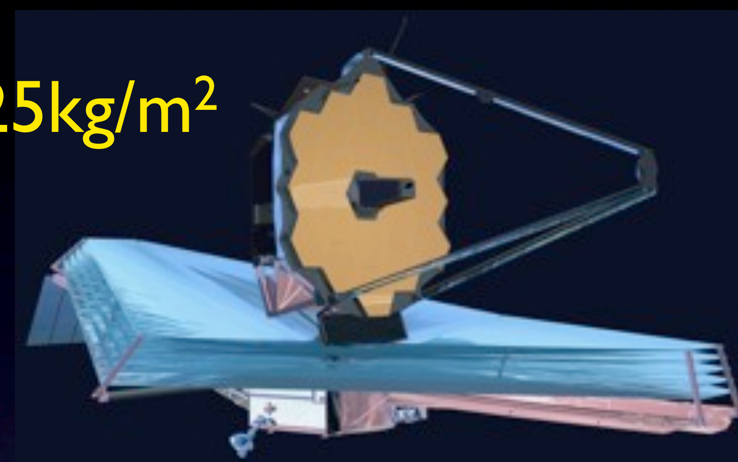
for example

HST 2.4m



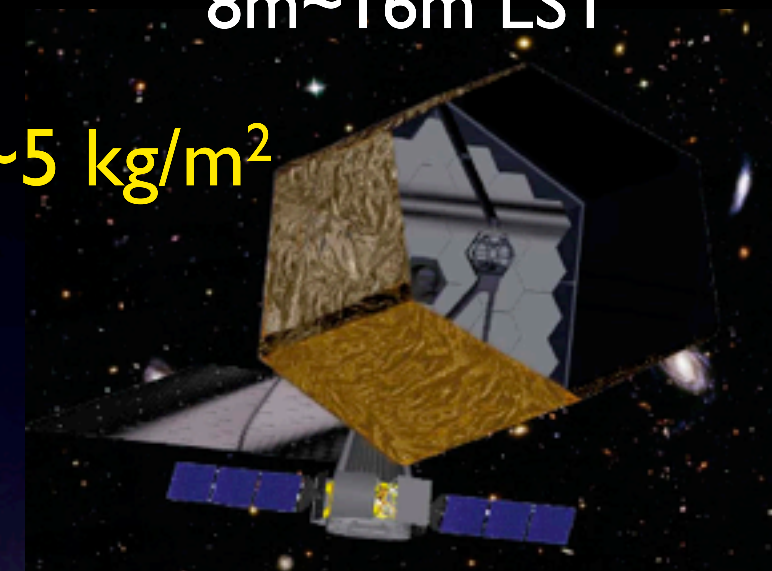
JWST 6.5m

~25kg/m²



8m~16m LST

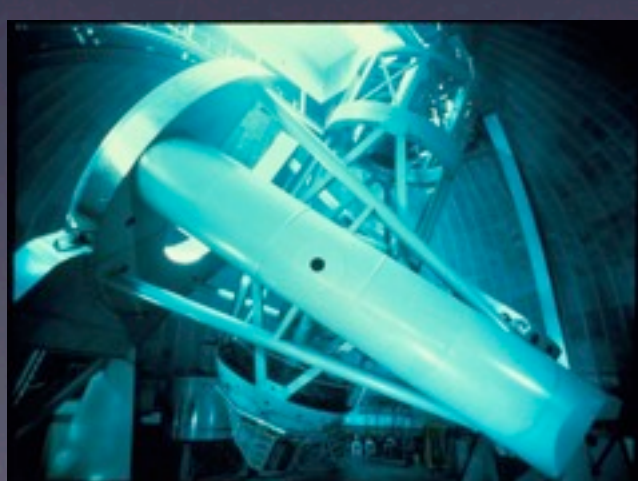
~5 kg/m²



Passive control

Active control

Fully active and adaptive control



Palomar 5m

Keck 10m

E-ELT/TMT 30m~40m

pathways to a large UVOIR space telescope

If Ares V is built by 2019 …

8-m monolithic mirror Telescope in ~2025 and/or 16-m segmented mirror Telescope in ~2030+

If Ares V is not built …

Delta IV HLV

9.2-m segmented mirror Telescope in ~2028 or Elliptical (light-weight) monolithic mirror Telescope in ~2028

Ares V payload to L2 = 65 mT, Delta IV HLV payload to L2 = 16 mT

The science is compelling

"Four hundred years after Galileo's discoveries via the first astronomical use of the telescope, the world's astronomers are once again using powerful new instrumentation to make startling discoveries of and about new planets, quite literally other worlds, which promise to once again transform our understanding of the nature of the Earth and of life's and humanity's places in the cosmos."

Ed Turner, 24th March 2009

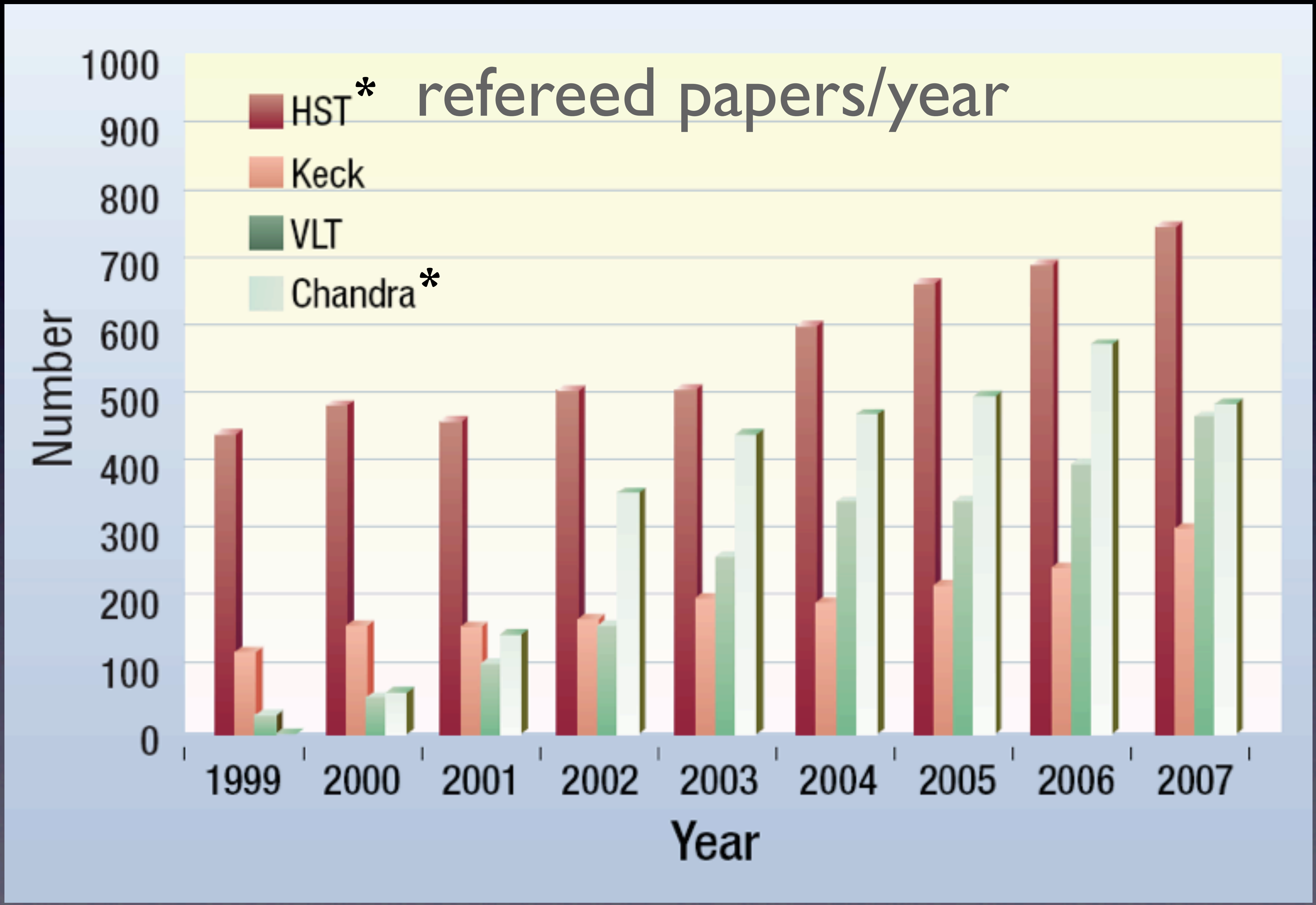
The Search for Life in the Universe @ STScI

however... summary of 132 science white papers submitted to Astro2010

Courtesy of http://www.wordle.net/, IBM Research media communications lab. - uniform use of “Exo-planets”

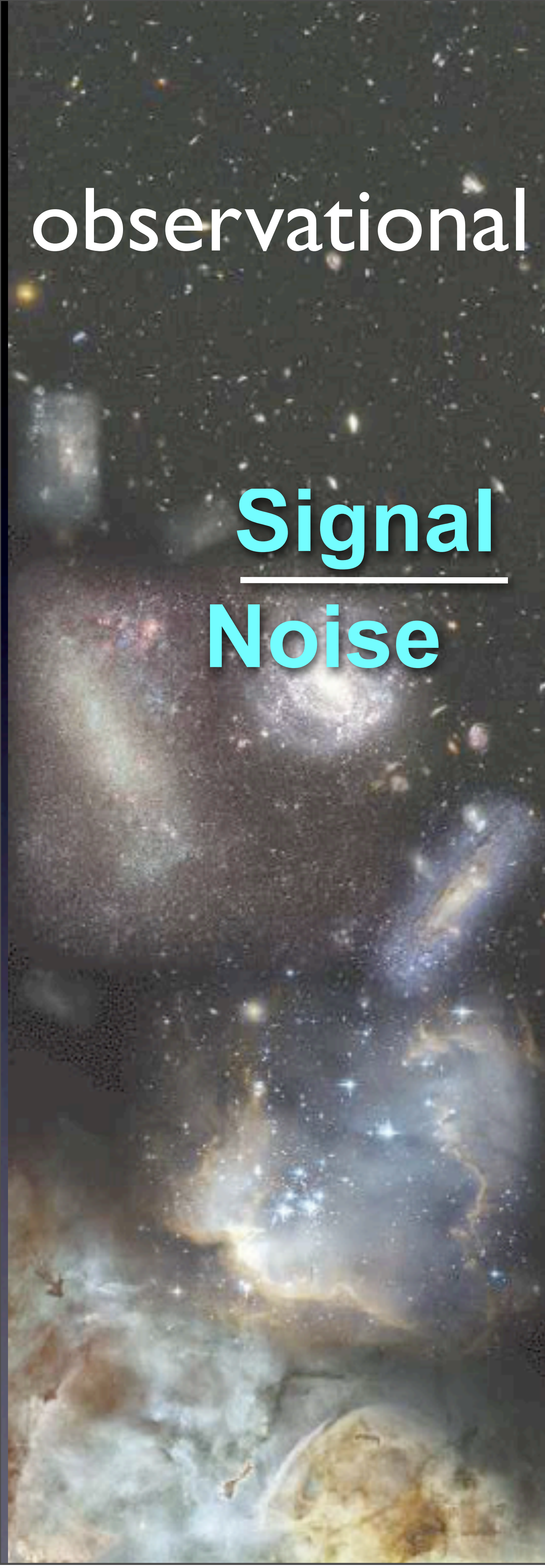
~85% of submissions do not reference “exo-planets”

the most productive "Flagships" have broad community participation hence support



* for these mission NASA provides substantial grant support to the community

observational astrophysics need flagships



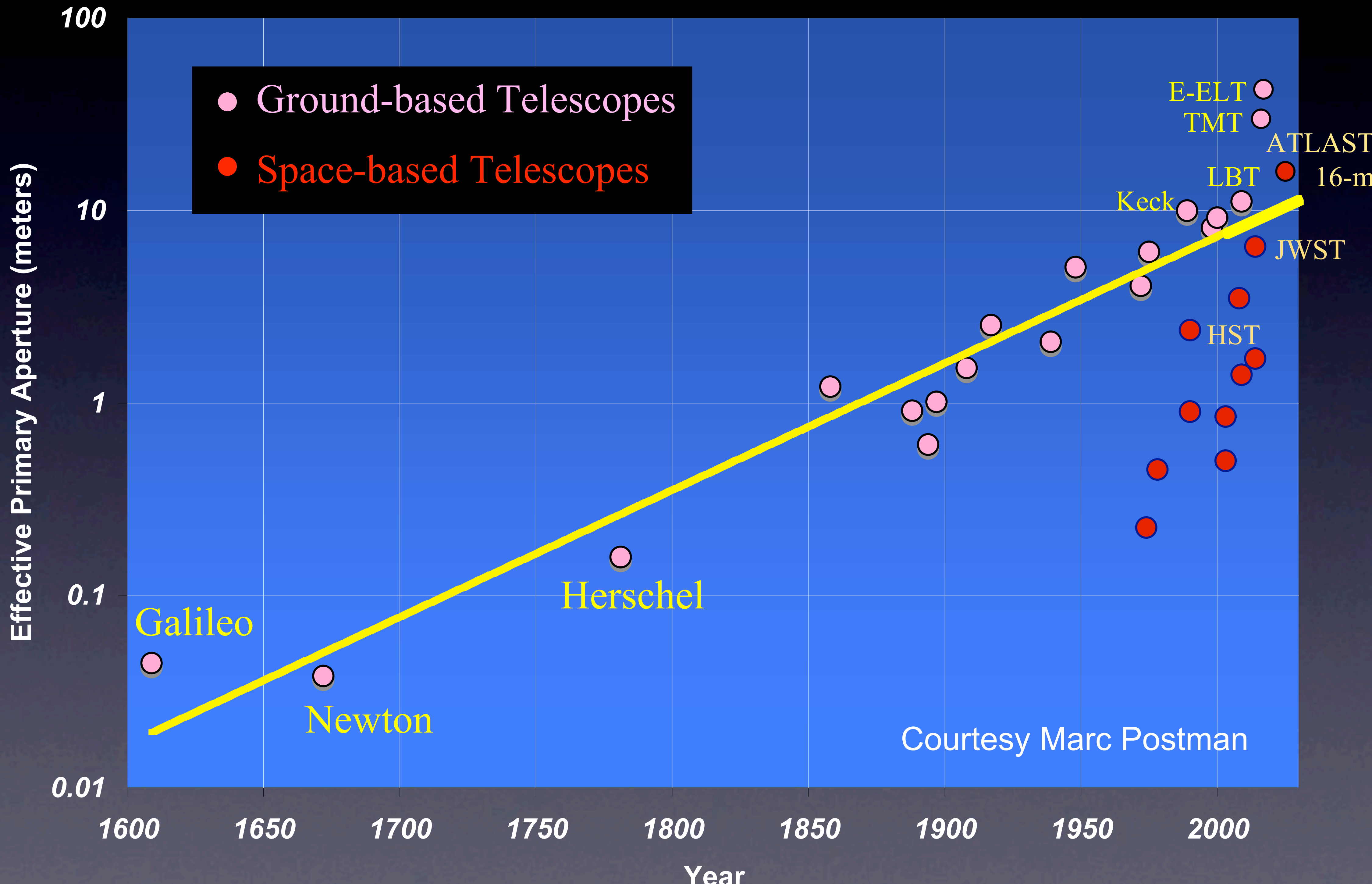
$$\frac{\textbf{Signal}}{\textbf{Noise}} \propto \frac{\textbf{Telescope Diameter}}{\textbf{Image size}} \times \sqrt{\frac{\mathbf{QE}_\lambda}{\mathbf{B}_\lambda}}$$

QE = detector quantum efficiency	~ 100%
B = sky, telescope background	~ low in space
Image size, over large FOV	~ small in space

Observational astrophysics remains a photon limited science and hence there is a compelling case for large aperture UV, Optical & Near-infrared telescopes in space

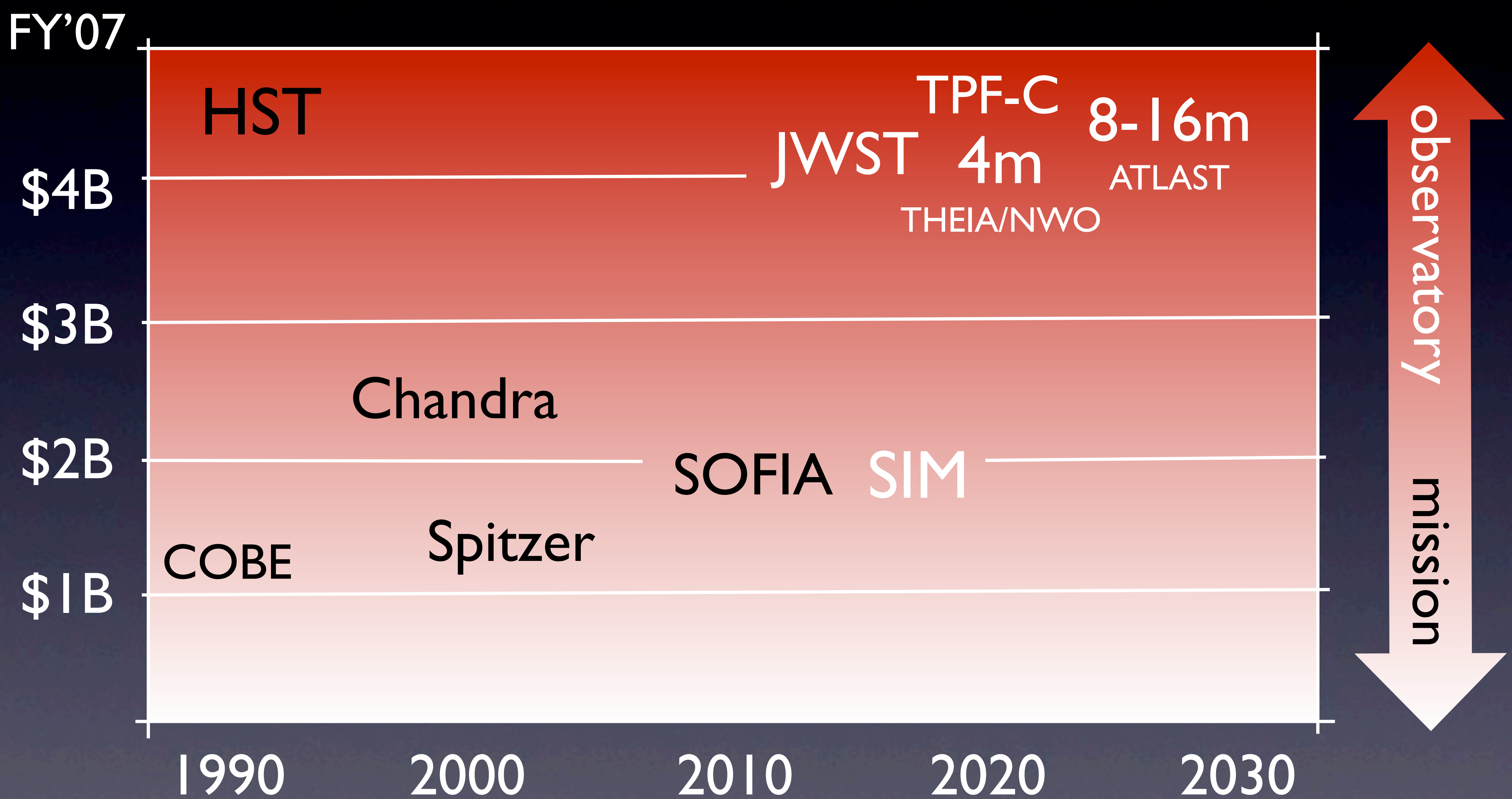
aperture growth driven by science, technological maturity

but also by philanthropy, science and/or industrial policy....

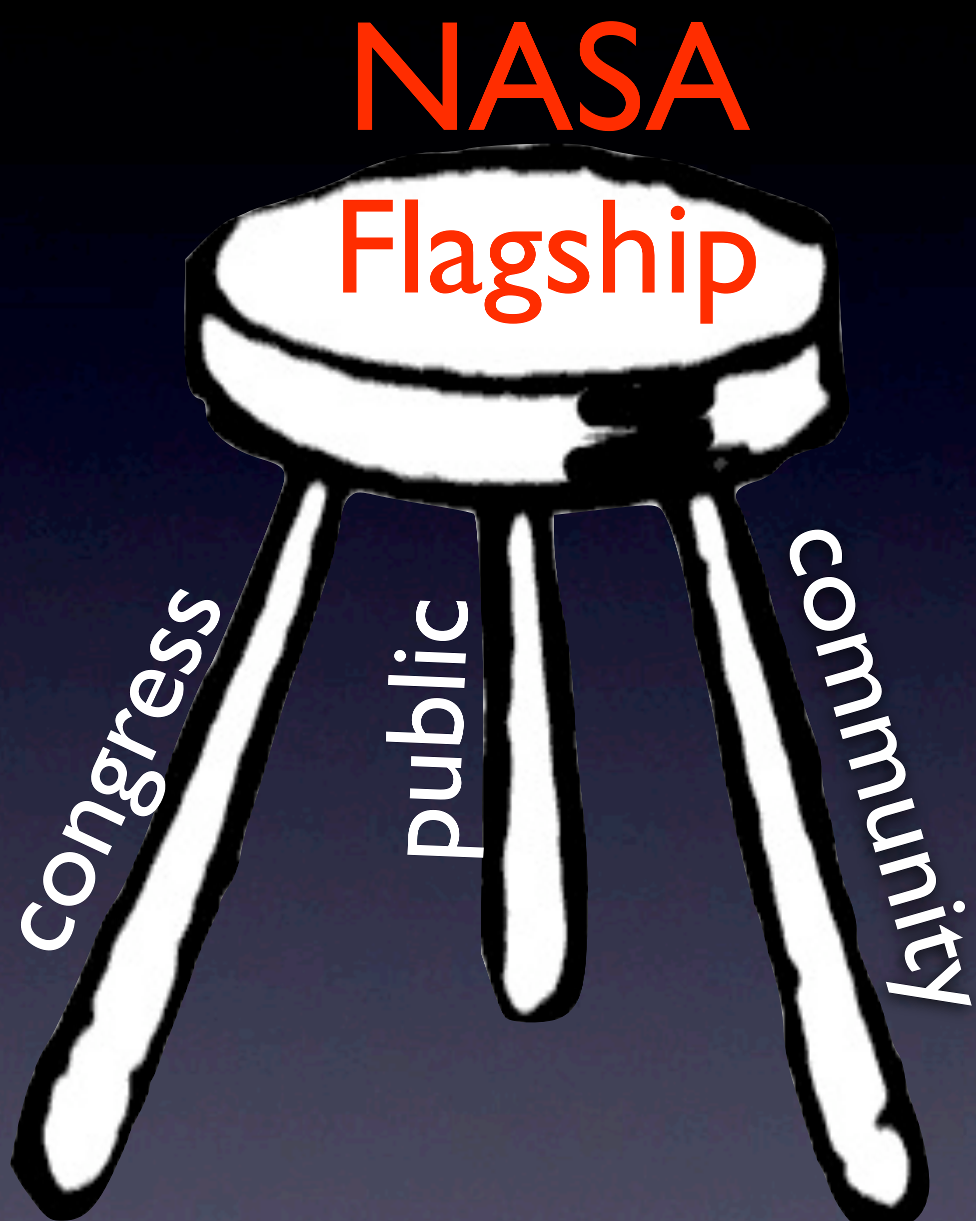


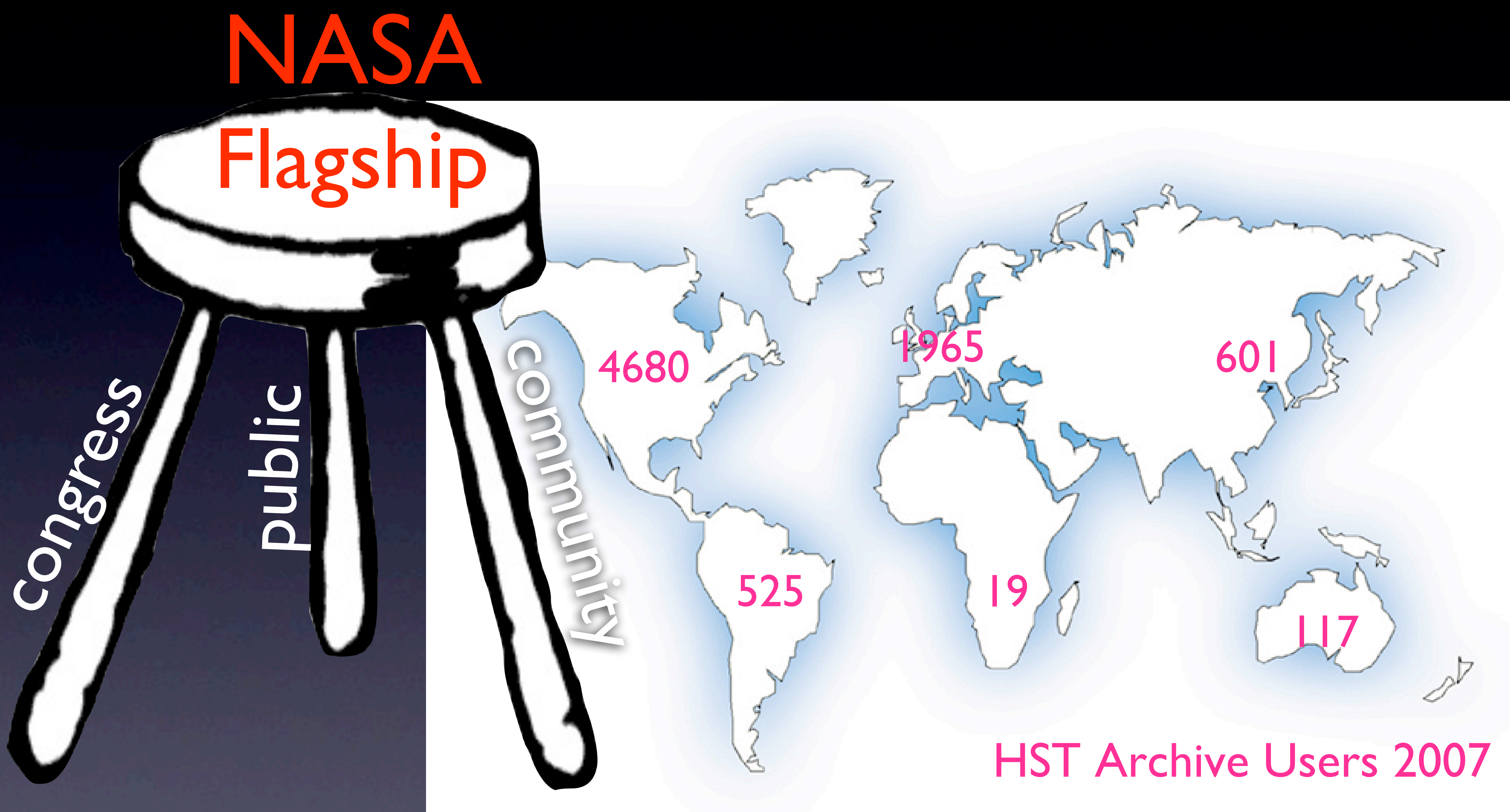
Primary Telescope Aperture vs. Time

flagship cost and 'expectations'



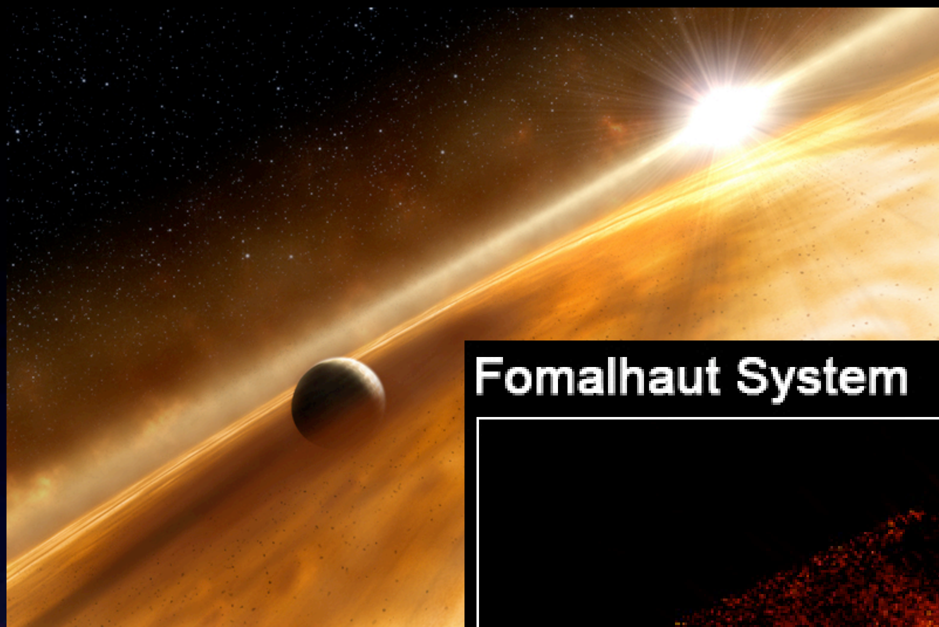
huge competition for the few slots in the top-right corner

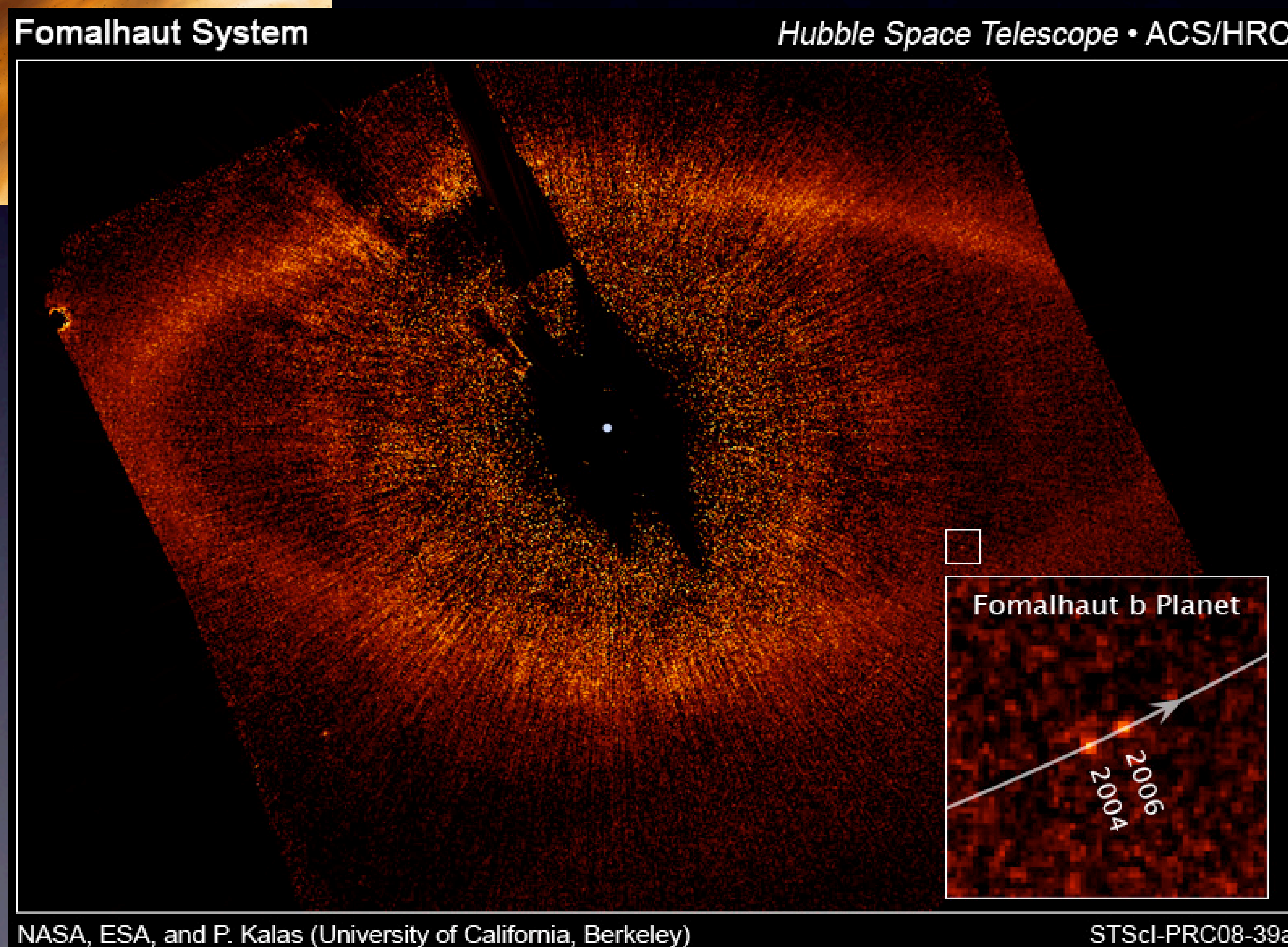

NASA
Flagship
congress
public
community


NASA
Flagship
congress
public
community
4680
1965
601
525
19
117
HST Archive Users 2007


June 15, 2020
Special Issue
TIME
We are not alone
NASA's Telescope
Discovers First Earth-like Planet
www.time.com

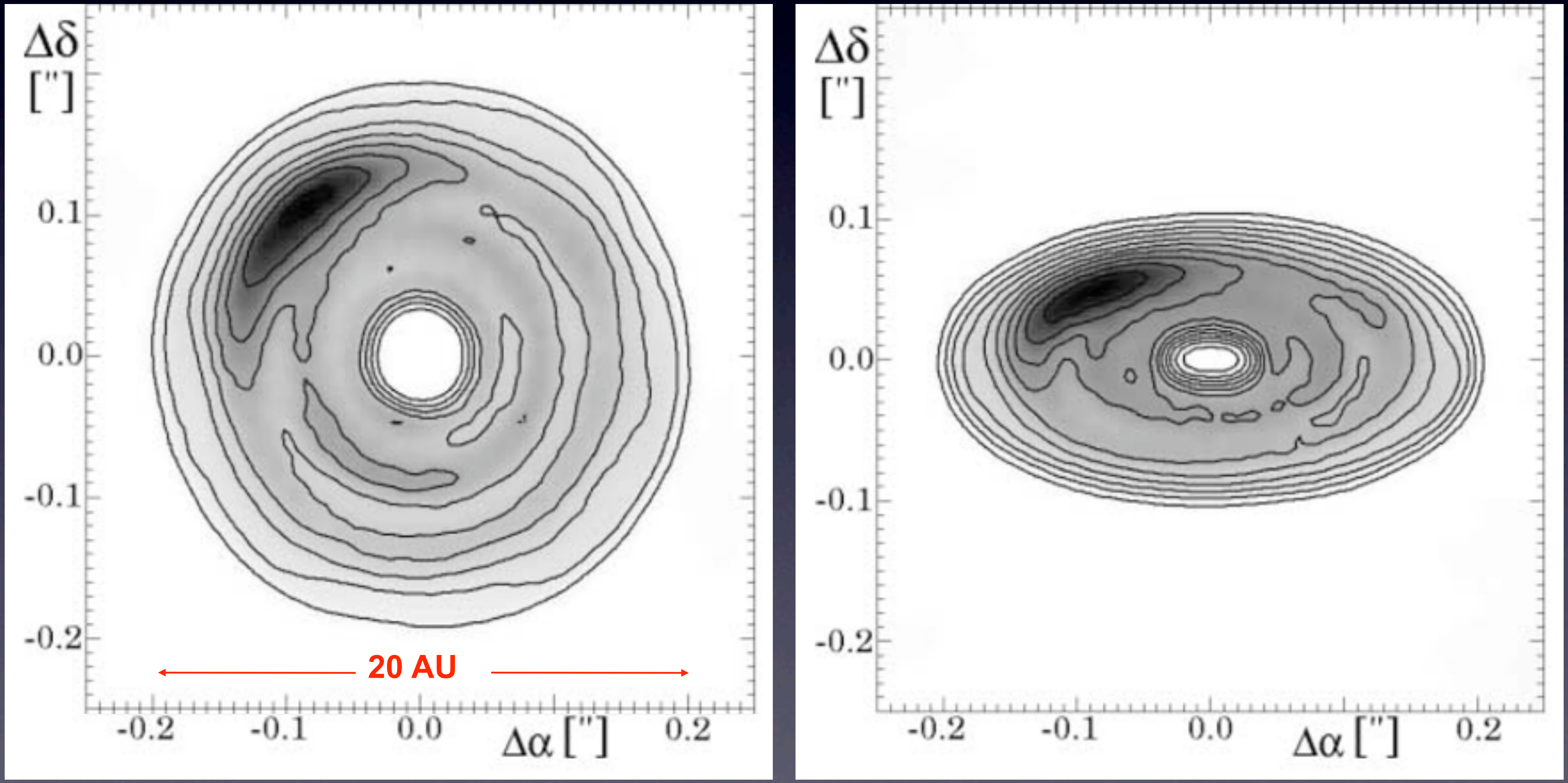
Hubble images its first planet outside our solar system





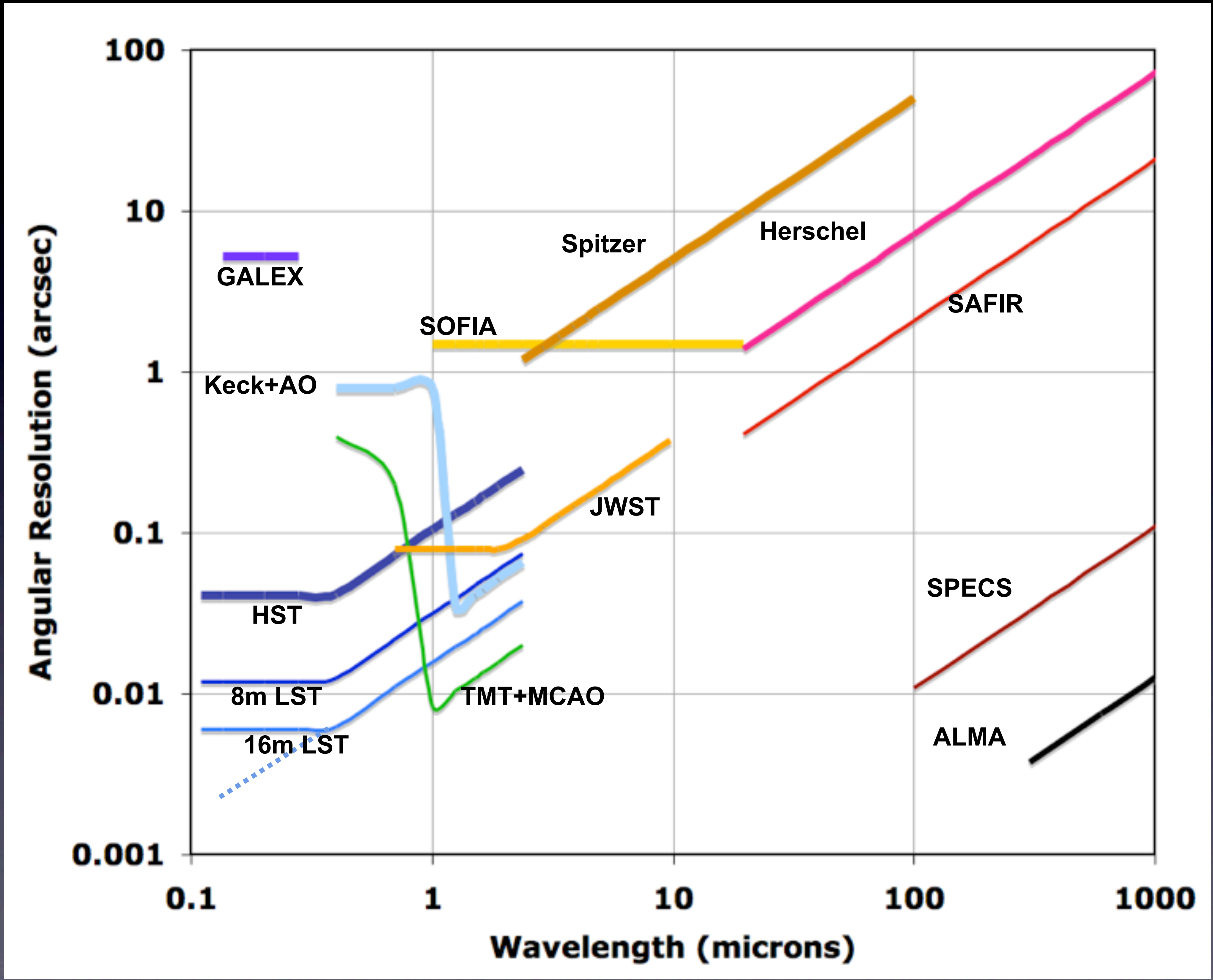
example: early evolution of proto-planetary disks

Simulated ALMA 900 GHz images of protoplanetary disk at distance of 50 pc (Wolf & Klahr ApJ, 2002)



From Marc Postman

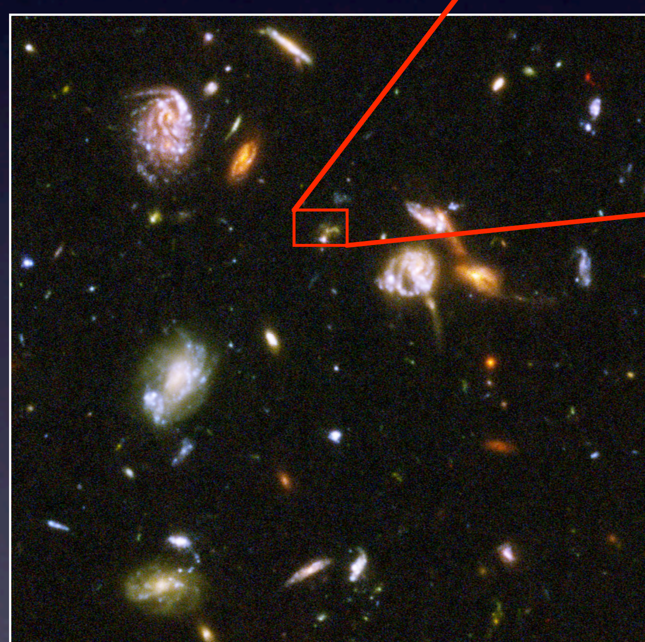
Multi-wavelength Angular Resolution



From Marc Postman

Figure derived from ExoPTF (Lunine et al. 2008)

"modern" galaxy evolution

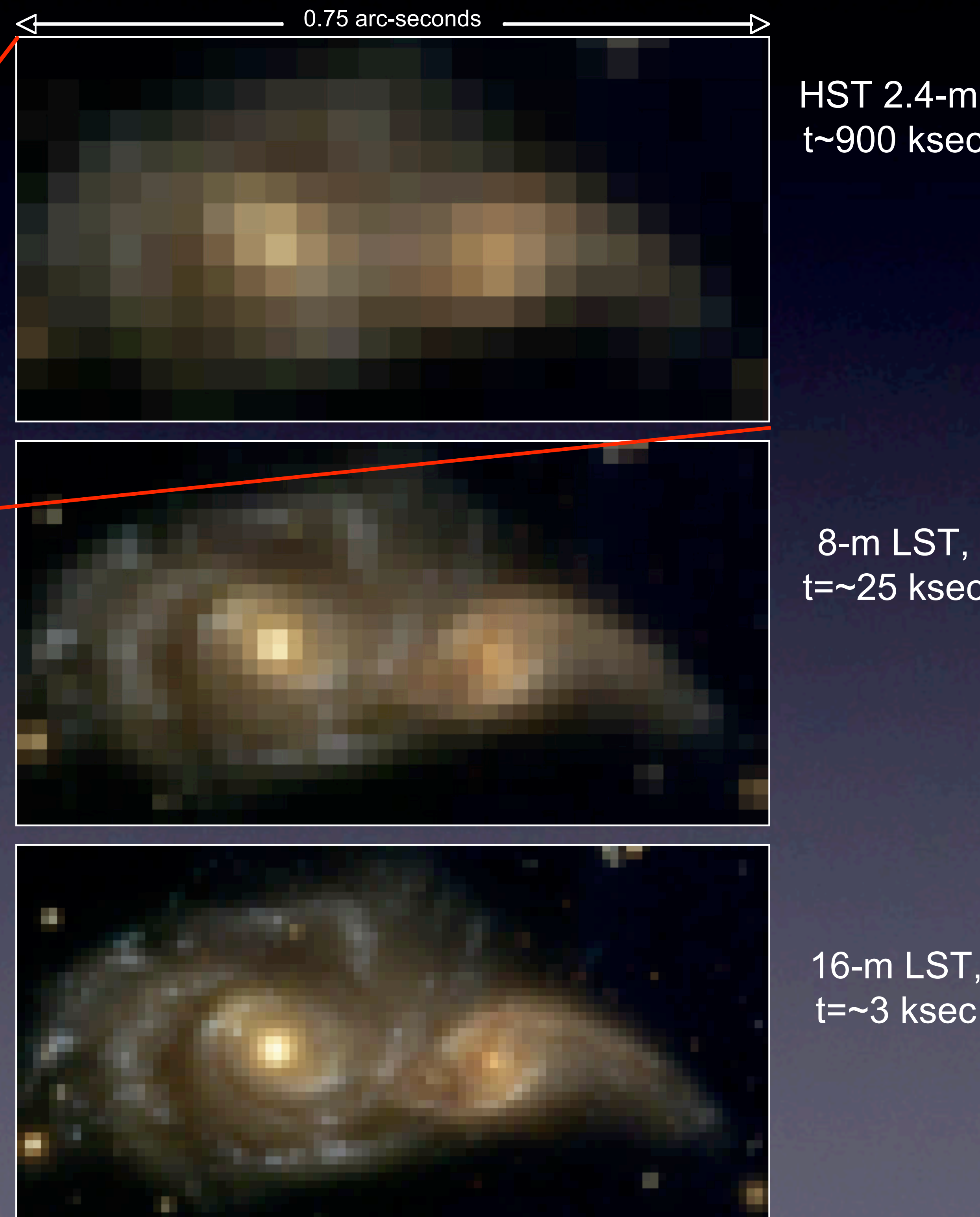


HST Ultra Deep Field

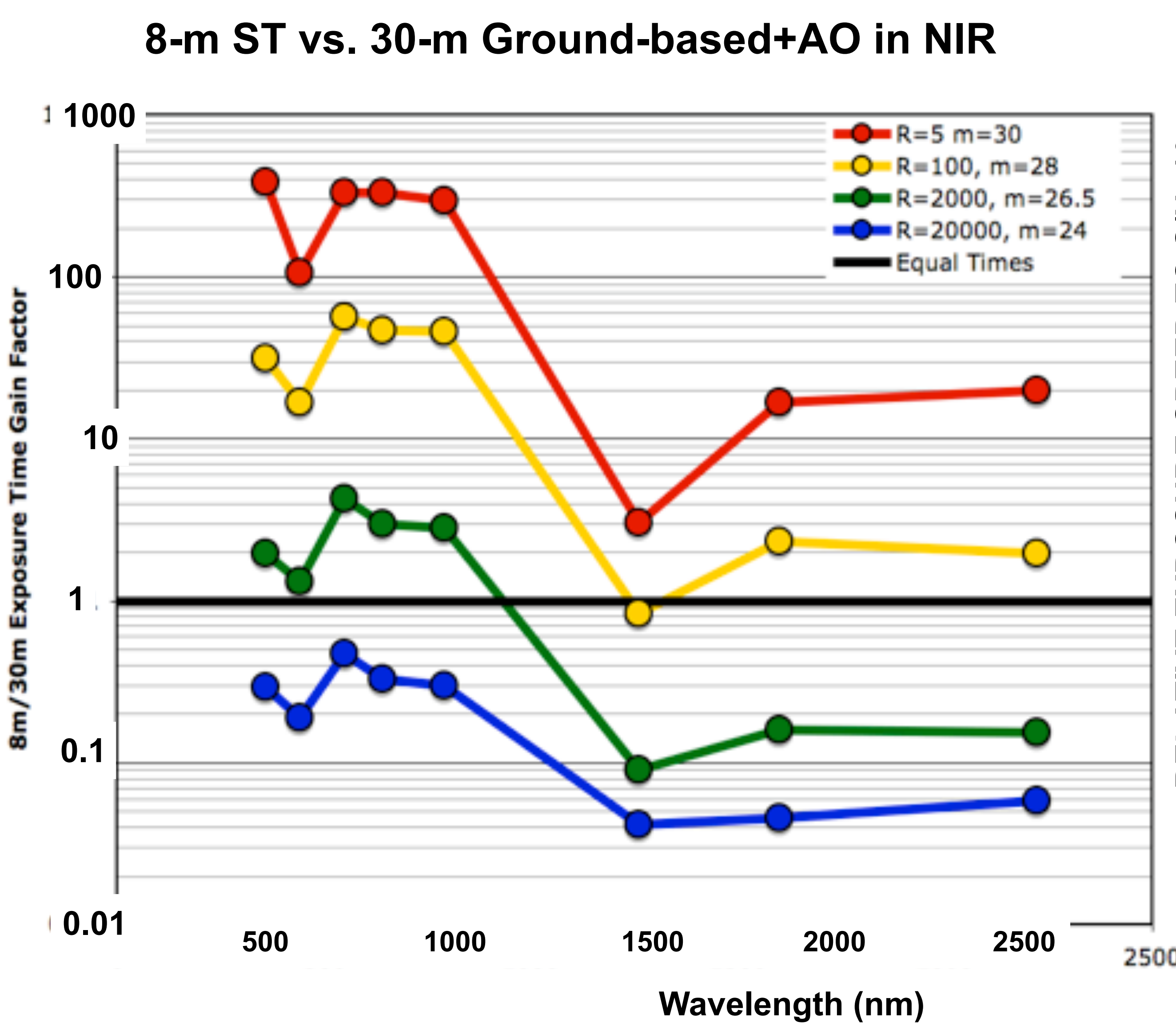
Faint Galaxy:

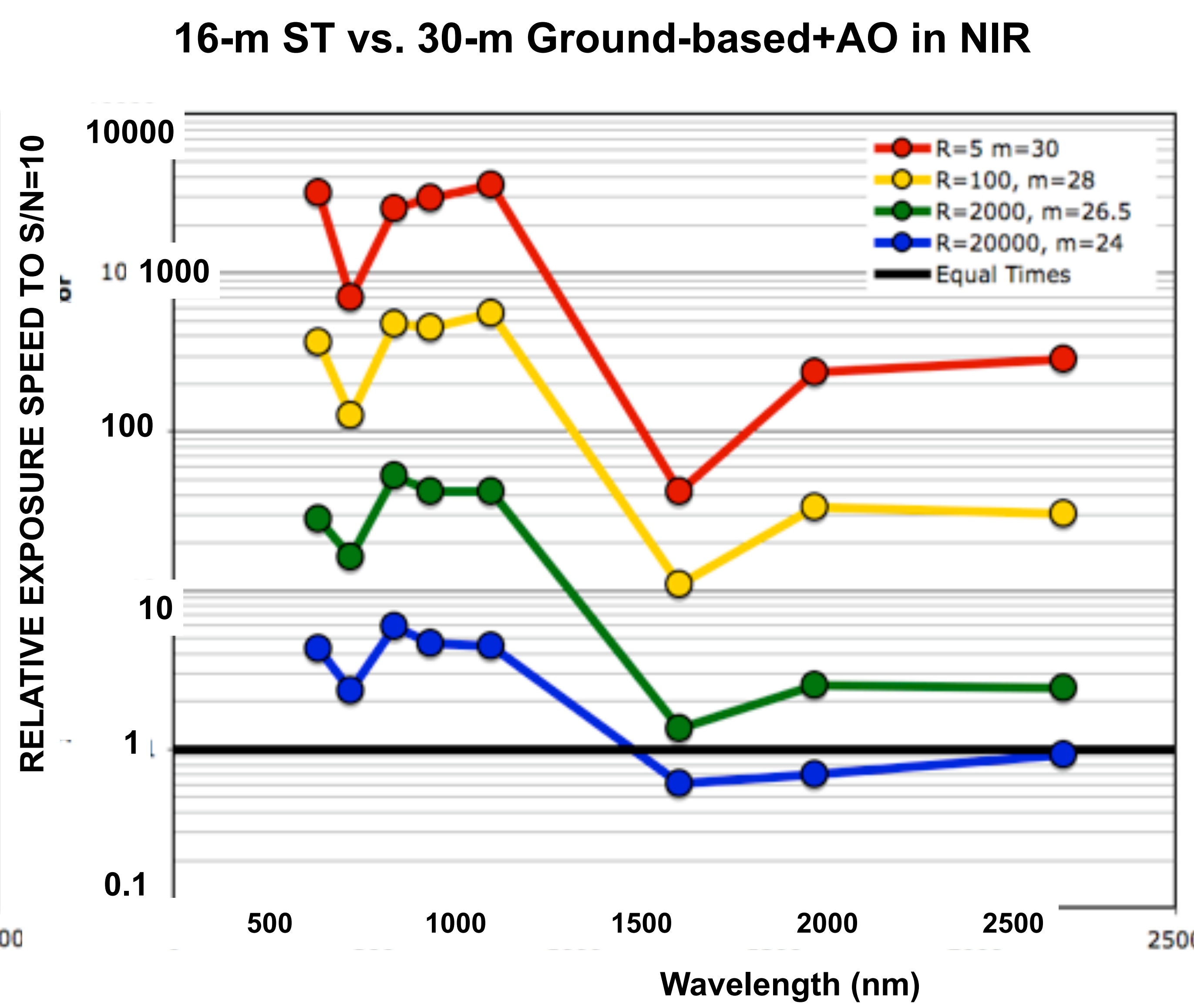
- 25.1 AB mag (330 nJy) in I-band
- 0.75 arc seconds across
- 2 "peaks" in light distribution
- Morphology unknown

Courtesy ATLAST Team



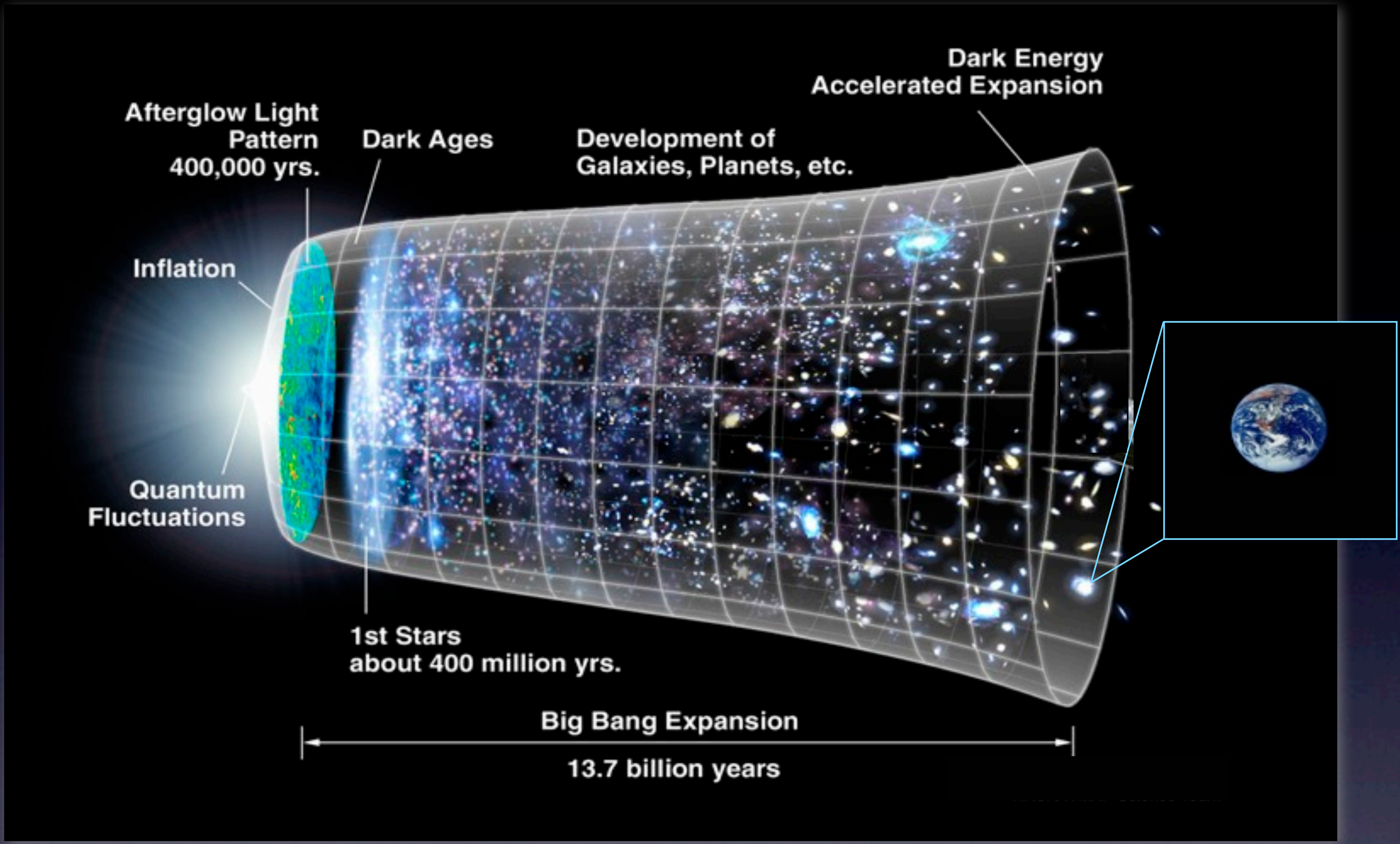
time gain factor





8-m ST faster than 30-m on ground for all imaging and for most R=100 low-res spectroscopy. 8-m also faster for med-resolution spectroscopy in optical band.

16-m ST faster than 30-m on ground for all imaging and spectroscopy except when R > few x 1000 in the NIR. Unique parameter space for hi-res spectroscopy in optical band.

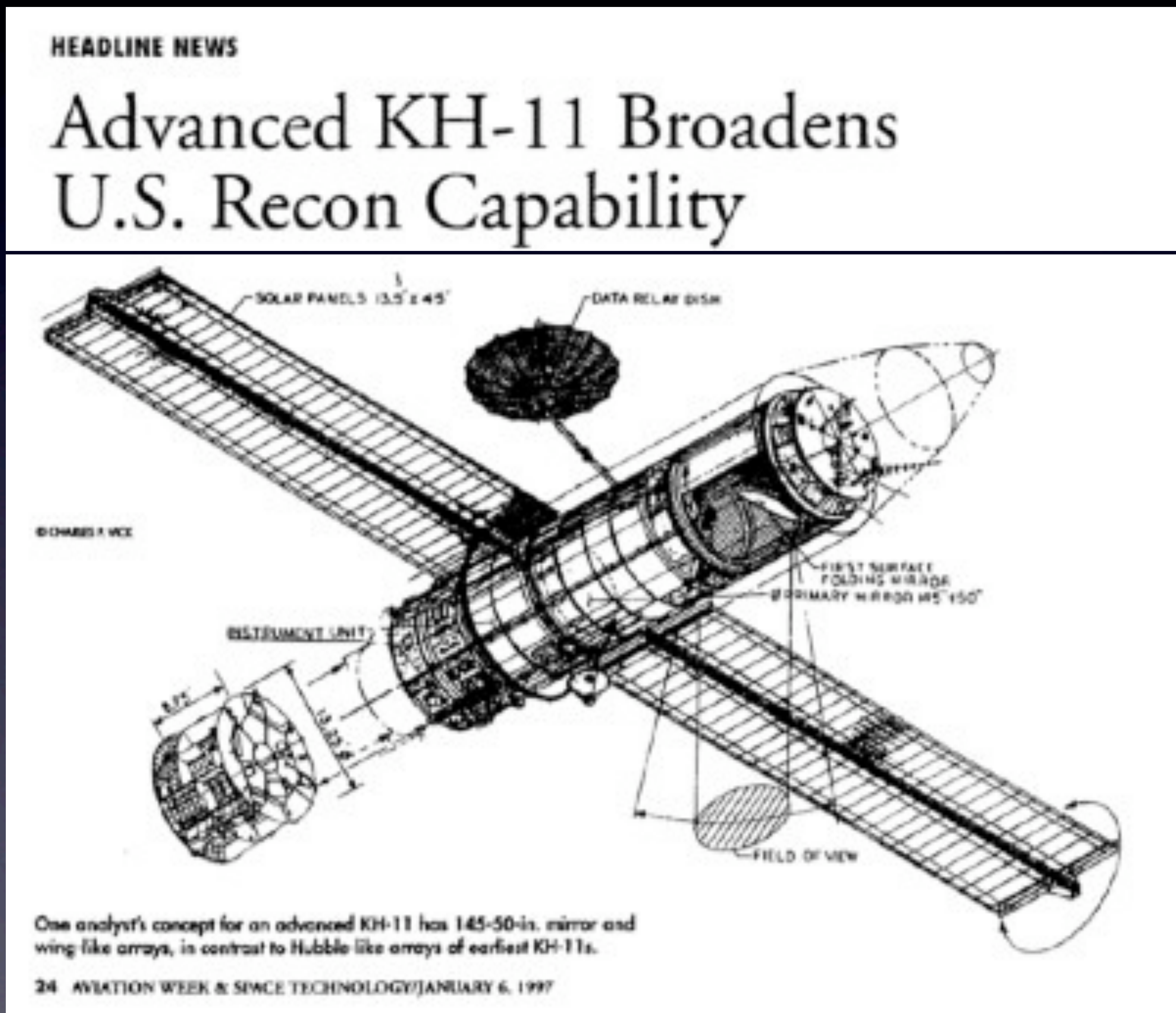


the most compelling science themes, the search for life

and

unraveling the complexity of the modern Universe - which led from the Big Bang to the emergence of a sustainable, habitable planet, require a generation of new and powerful space telescopes

Space Science has always built on investments made "elsewhere"


HEADLINE NEWS

Advanced KH-11 Broadens U.S. Recon Capability

One analyst's concept for an advanced KH-11 has 145-50-in. mirror and wing like arrays, in contrast to Hubble like arrays of earliest KH-11s.

The two main contractors that built the telescope had allegedly extensive experience building this kind of spacecraft - but not much is known publicly about these programs.

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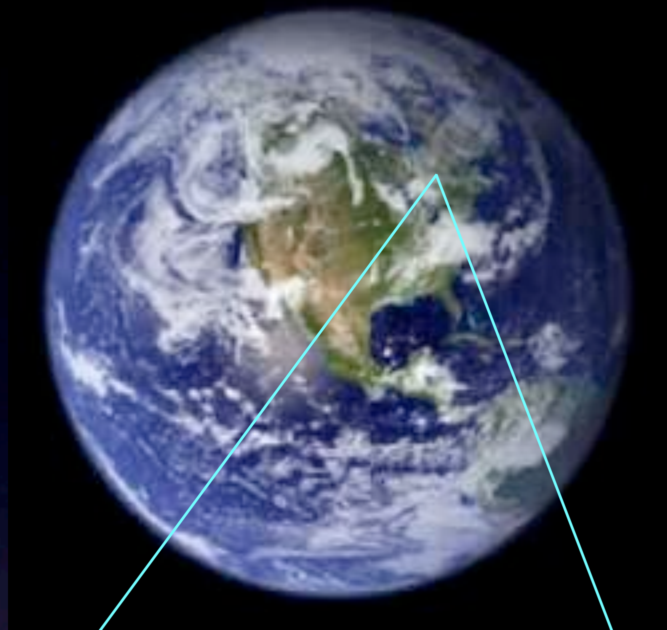
24 AVIATION WEEK & SPACE TECHNOLOGY/JANUARY 6, 1997

"How [have] we in astronomy come so far? … By standing on the shoulders of military/industrial giants. … These larger scale efforts have been central to our success. … Where military or industrial support did not exist and we had to go ahead on our own, progress has been much slower."

Martin Harwit,
March 1999

The two main contractors that built the telescope had allegedly extensive experience building this kind of spacecraft - but not much is known publicly about these programs.

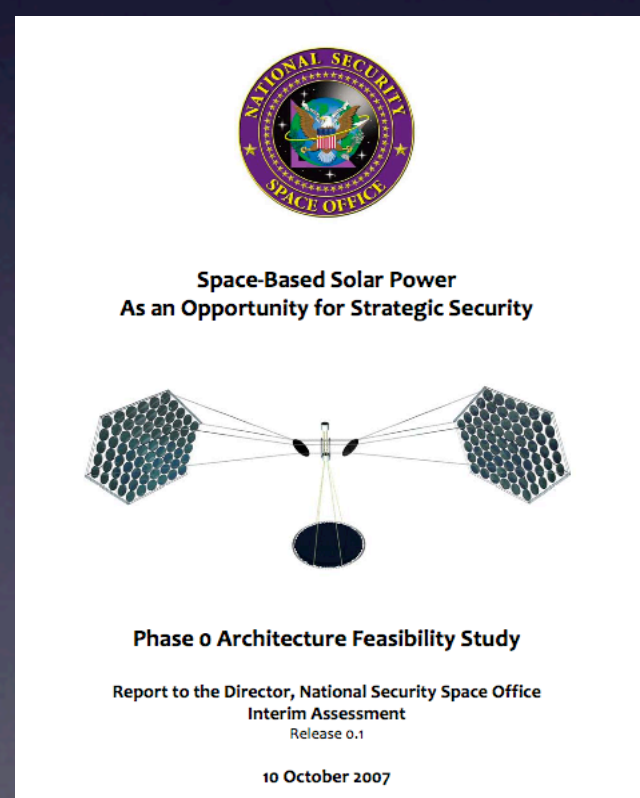
Large space based technologies rely on, and can enable multidisciplinary partnerships



Geostationary orbit

National & Environmental Security

Solar collectors in space



NATIONAL SECURITY SPACE OFFICE

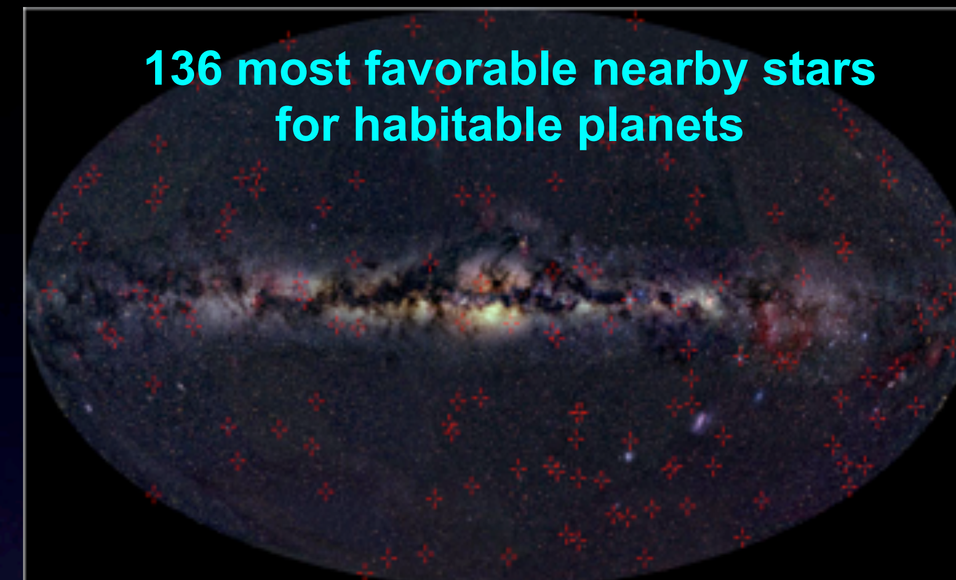
Space-Based Solar Power
As an Opportunity for Strategic Security

Phase 0 Architecture Feasibility Study

Report to the Director, National Security Space Office
Interim Assessment
Release 0.1

10 October 2007

Energy



"I would like to see a reconnaissance of the planetary systems around the nearest 100 stars."

Carl Sagan, 1994 (paraphrase)

Are we alone?

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–

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		Observable?
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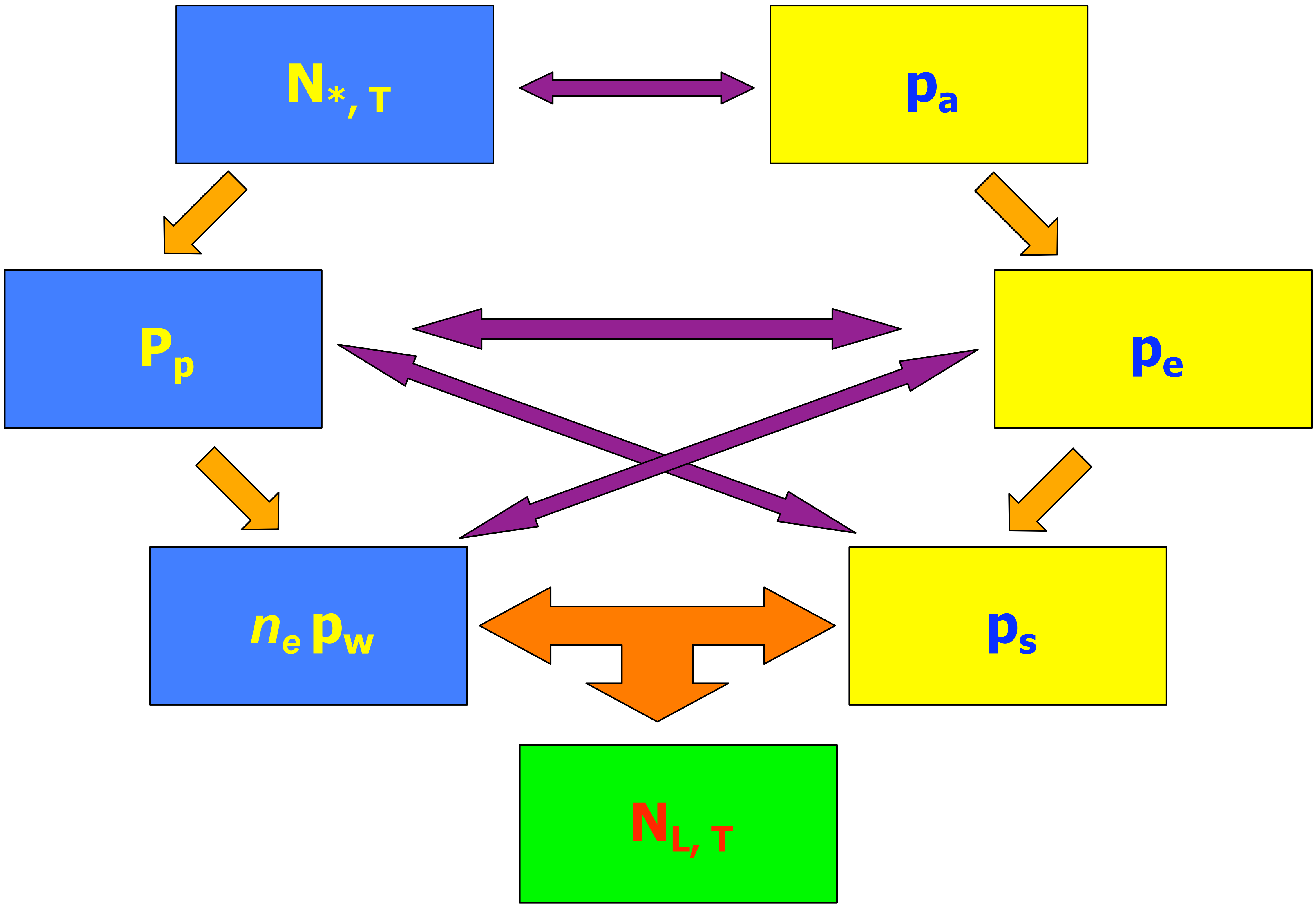
Prob. of planet system:	$p_p = f(Z, m)$	✓
No. of terrestrial planets	$n_e = n\,(0.1 m_e < m_p < 10\, m_e)$	✓
Prob. of liquid water	$p_w = f(n_b, \varepsilon, r_{orbit}, L_*)$	✓
Prob. of abiogenesis	$p_a = f\,(?)$	?
Prob. of evolution	$p_e = f(t, Z, T)$	✓
Prob. of survival	$p_s = f(t, environment)$	✓

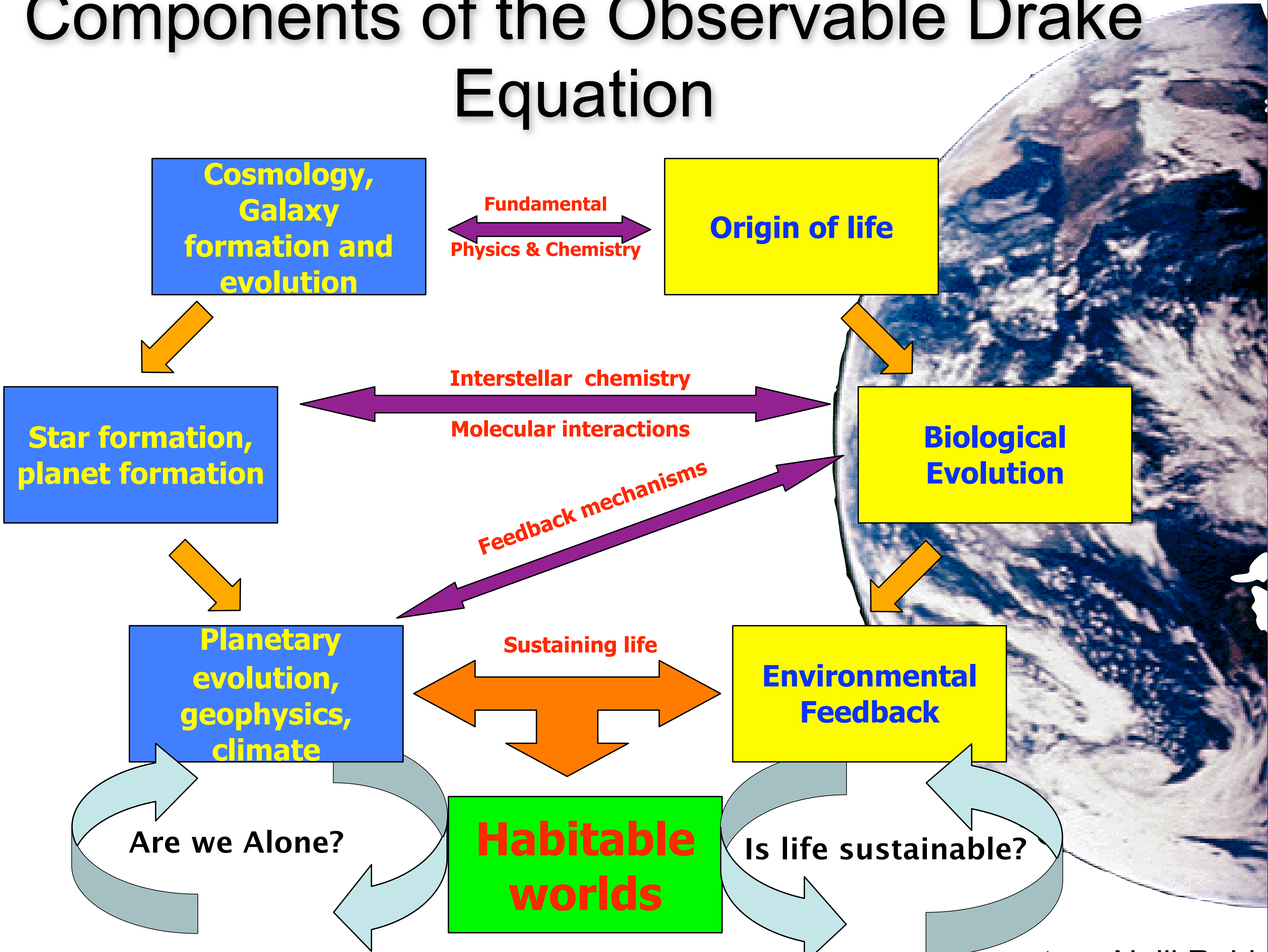
courtesy Neill Reid

Components of the Observable Drake Equation



courtesy Neill Reid

Components of the Observable Drake Equation



courtesy Neill Reid

Roadmap from “Exoplanet Community Report”
- Ed.by *P. R. Lawson, W. A. Traub and S. C. Unwin*

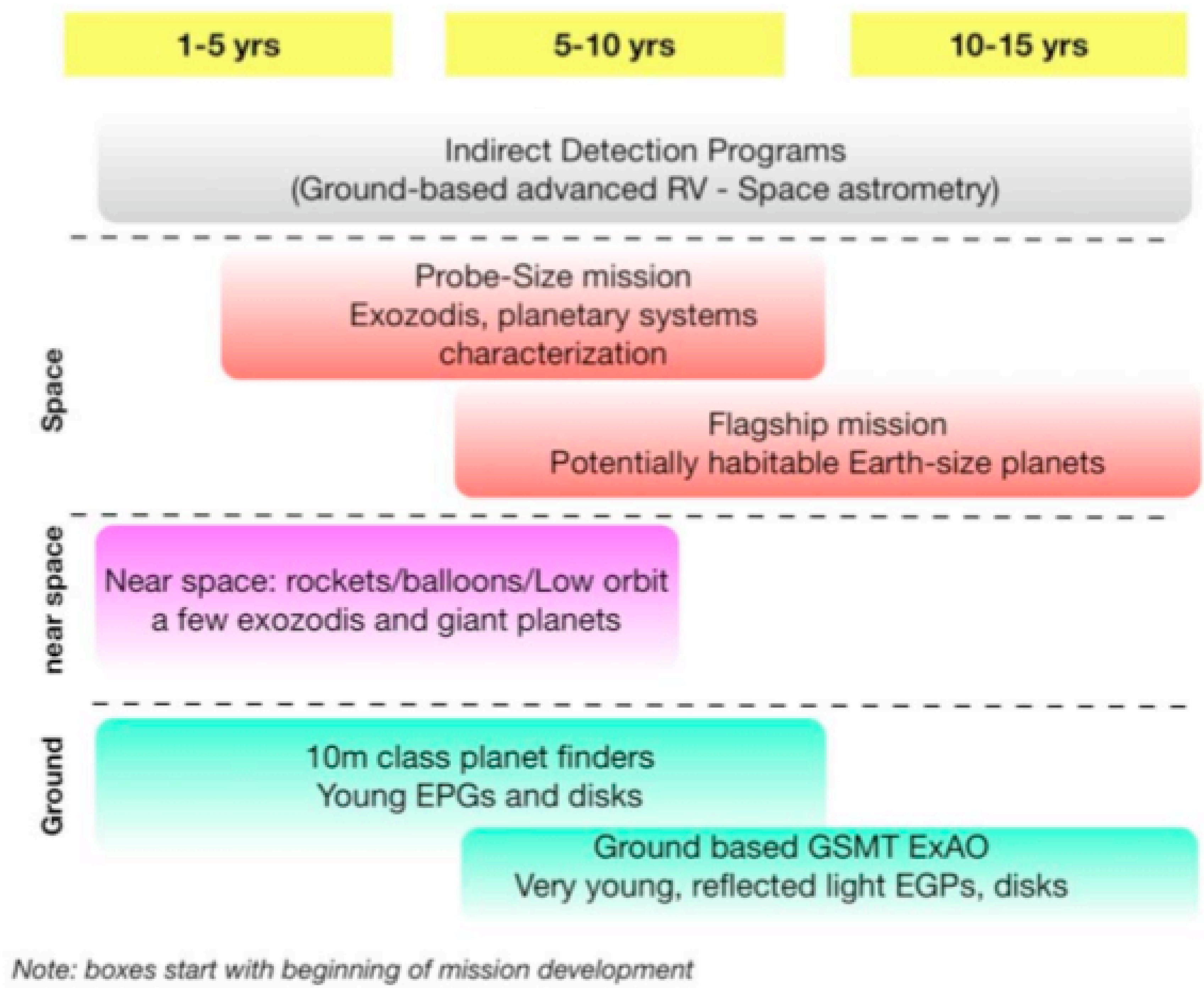


Figure 3-4. Range of relevant mission scales for direct imaging to enable a complete scientific and technological program. (R. Soummer, Space Telescope Science Institute, and M. Levine, JPL)

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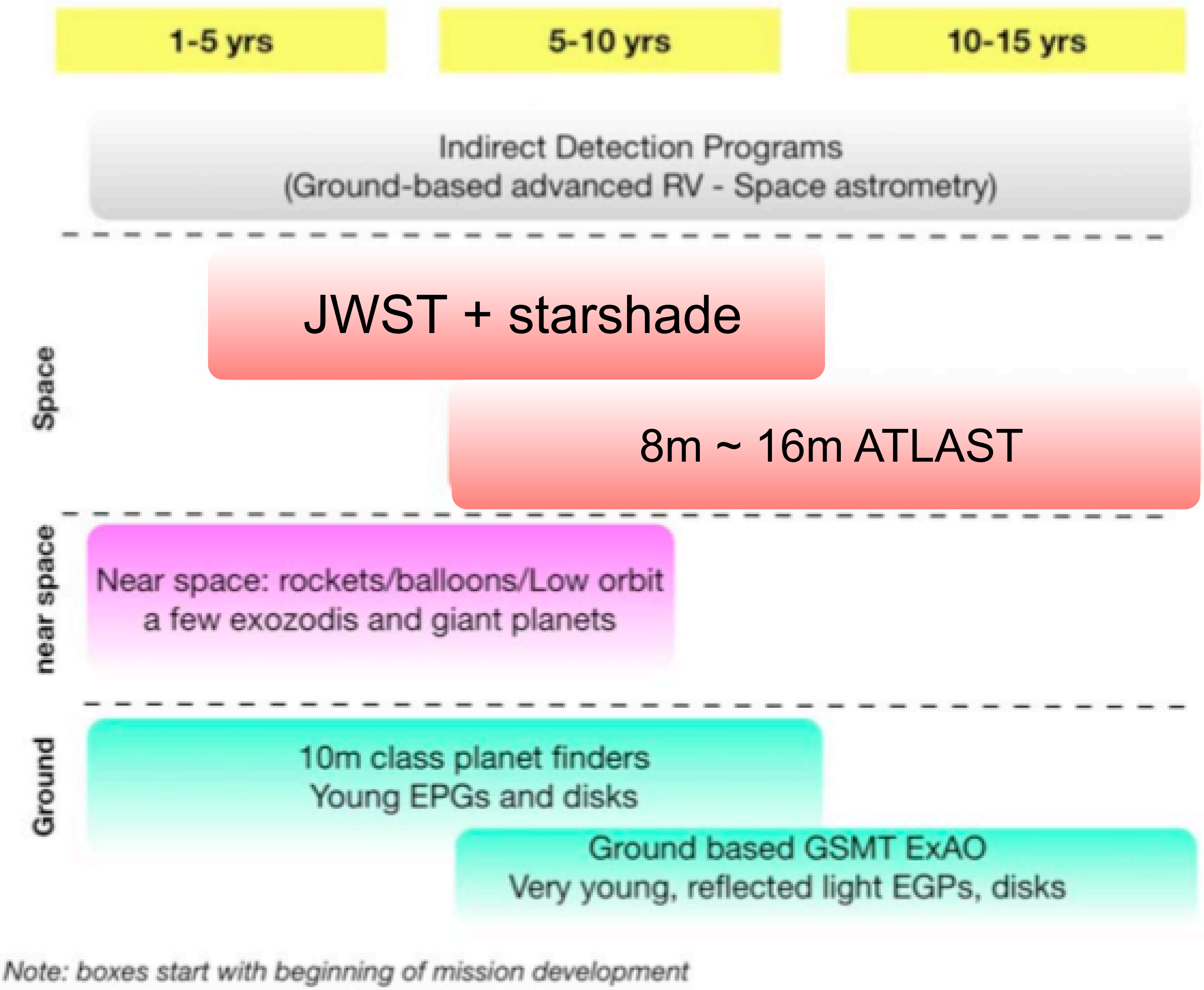
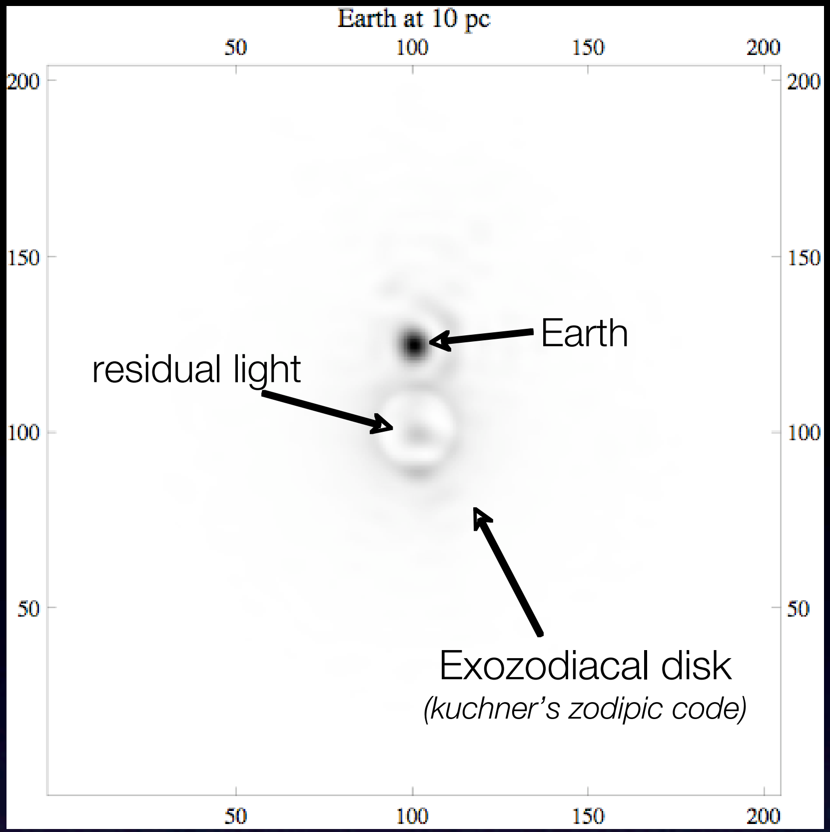
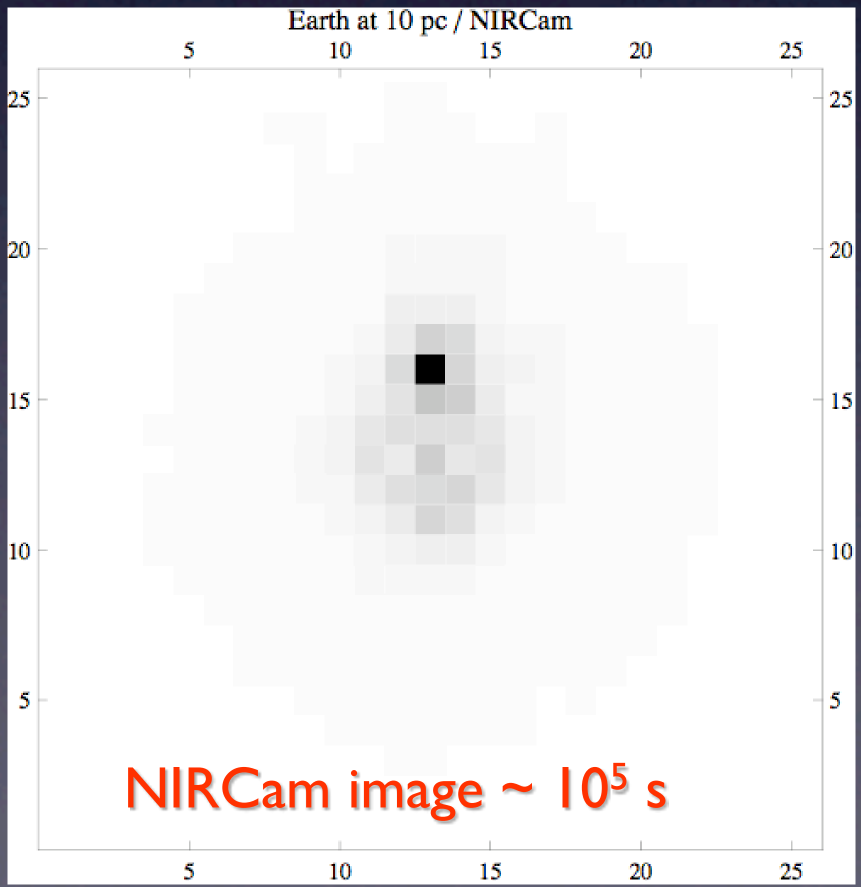


Figure 3-4. Range of relevant mission scales for direct imaging to enable a complete scientific and technological program. (R. Soummer, Space Telescope Science Institute, and M. Levine, JPL)

JWST with star-shade



Sun at 10pc with Earth 1e-10 contrast, JWST's pupil and OPD



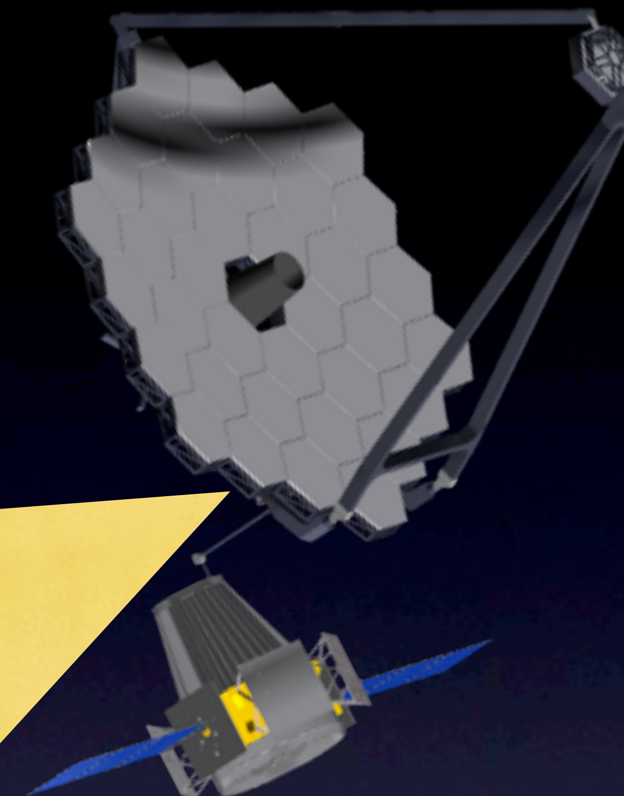
- Tests a key technology
- Measures zodiacal light
- Can undertake spectroscopy of Jupiter's and "super-earths"
- Has the potential to deliver the first "pale blue dot"

courtesy Remi Soummer, STScI

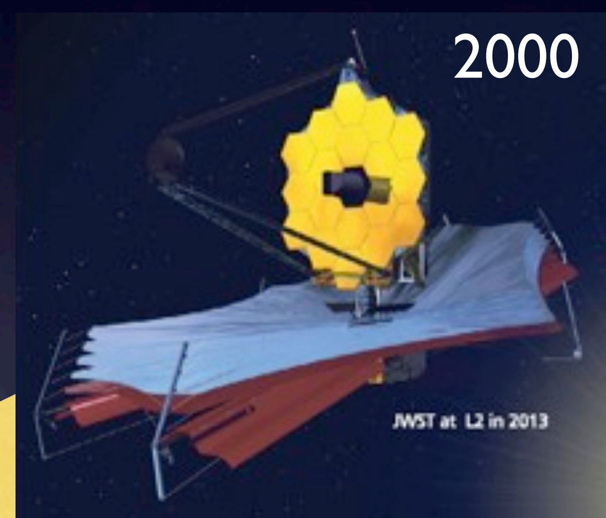
The Challenge

"Incrementalism is innovation's worst enemy. We don't want continuous improvement, we want radical change."

2020



16m ~ $4.5B (FY07)



6.5m ~ $4B (FY07)

2.4m ~ $4.5B (FY07)

focused investments,
and partnerships
should be able to deliver a
flagship class mission by 2020

within the next decade or so, we will have the capability to search for the signatures of life in our solar neighborhood.

we need to build a broad collation to support this endeavor, then our generation will be uniquely positioned "to relate causally the physical conditions during the Big Bang to the development of RNA and DNA[1]."

1. Riccardo Giacconi,

- Backup

NASA priorities in the next decade

The “Gap”

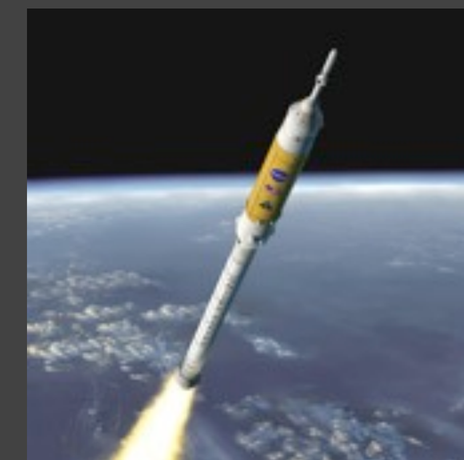
The Station

The Planet

Everything else…

NASA priorities in the next decade

The "Gap"



The Station

The Planet

To inspire the Nation